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Discover the wonders of the universe

In my lifetime there have been some pretty epic celestial events, arguably the most spectacular of which have involved comets. These periodic visitors to our Solar System trailblaze their way around the Sun, occasionally putting on a light show that leaves an indelible mark on human history.

It's been nearly 30 years since Halley's comet last made it's pass, lighting up the night sky long after my bedtime – I distinctly remember stomping upstairs to my room, thinking that I'd be in my eighties before I got to see it again. Luckily, 11 years later the cosmos put on what became one of the most impressive spectacles in living memory, as the great comet Hale-Bopp blazed across the Northern Hemisphere. It remained visible to the naked eye for an incredible 18 months, before it headed back out of the Solar System to continue its millenia-long orbit of the Sun, having been slightly perturbed by Jupiter.

Hale-Bopp is my observational highlight of recent years, but for many this will be outranked by 1994's comet Shoemaker-Levy 9, whose orbit was also changed by our Solar System's biggest planet, this time to catastrophic effect. On the 20-year anniversary of this memorable collision between gas giant and speeding comet, **All About Space** tells the epic story of its discovery (on page 41) and speaks to one of its co-finders, the amateur astronomer David Levy.

It serves to remind us that, despite the almost incomprehensible evolutionary timescale of the cosmos, our night sky is still changing and is so vast, even a lowly backyard amateur can make a monumental contribution to astronomy.

Ben Biggs
Editor

Crew roster

David Crookes

- If Crookes had a billion dollars, he'd spend it on his own, personal, giant telescope in his back garden

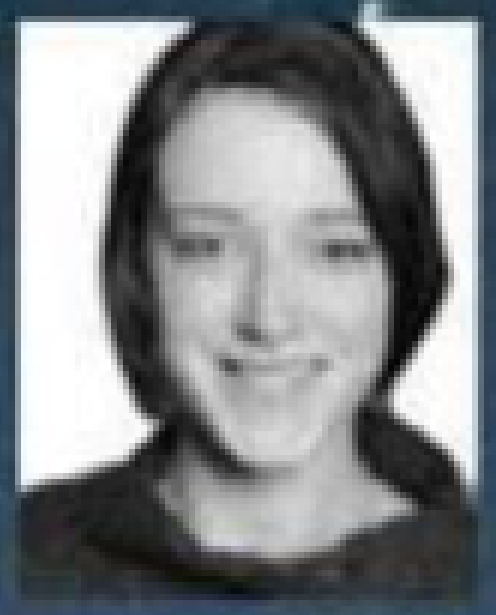
Gemma Lavender

- Gemma reminisces fondly on the day Shoemaker-Levy 9 put a show on for the world

Giles Sparrow

- It took most of Giles' massive brain power to consider R136a1, the massive Wolf-Rayet star

Laura Mears



- Ever wonder how astronomy has got to where it is today? Laura shows us on page 28

> "I was just amazed at what I was seeing – really dark black spots across the entire face of Jupiter"
>
> **David Levy, astronomer**

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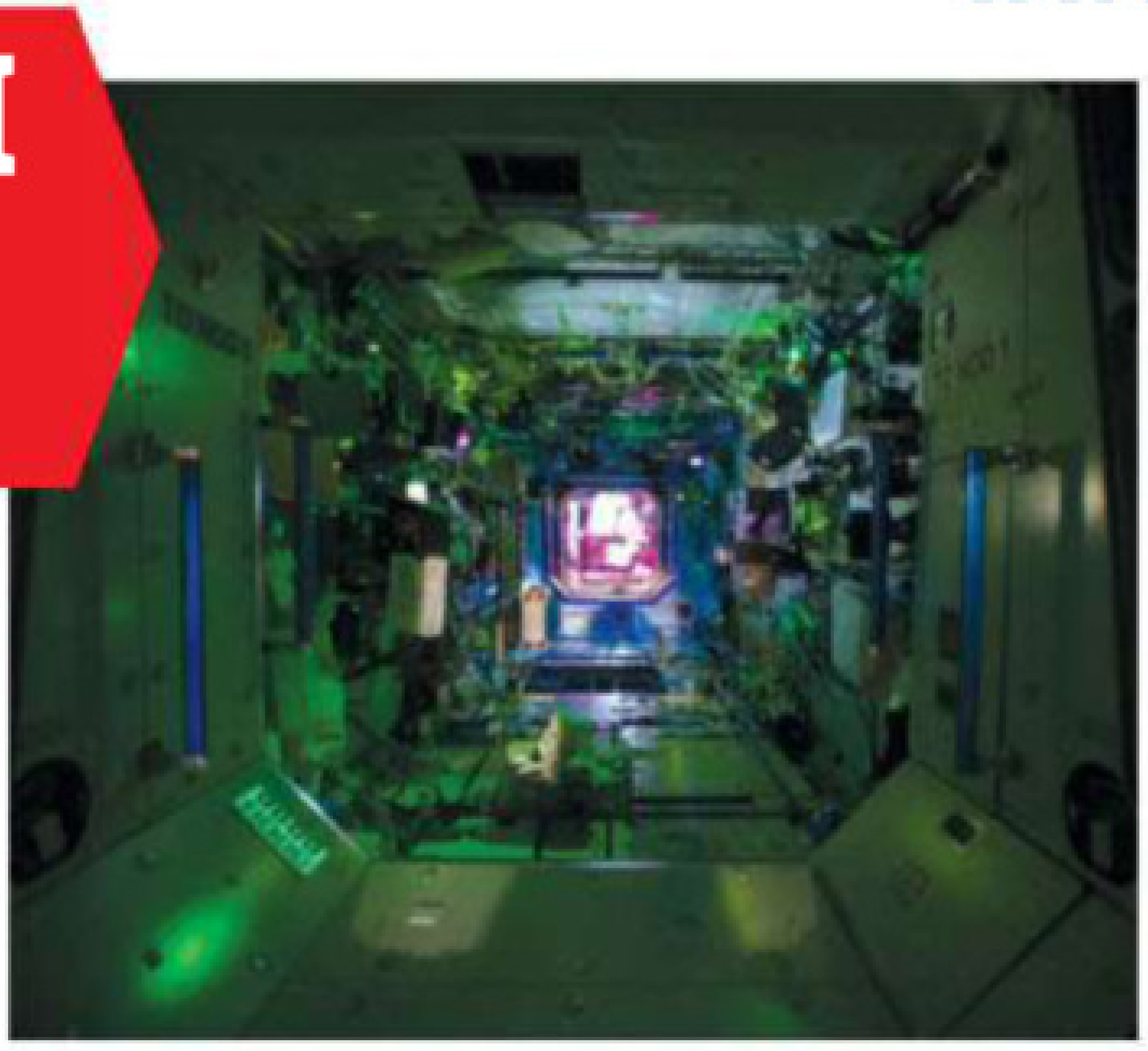

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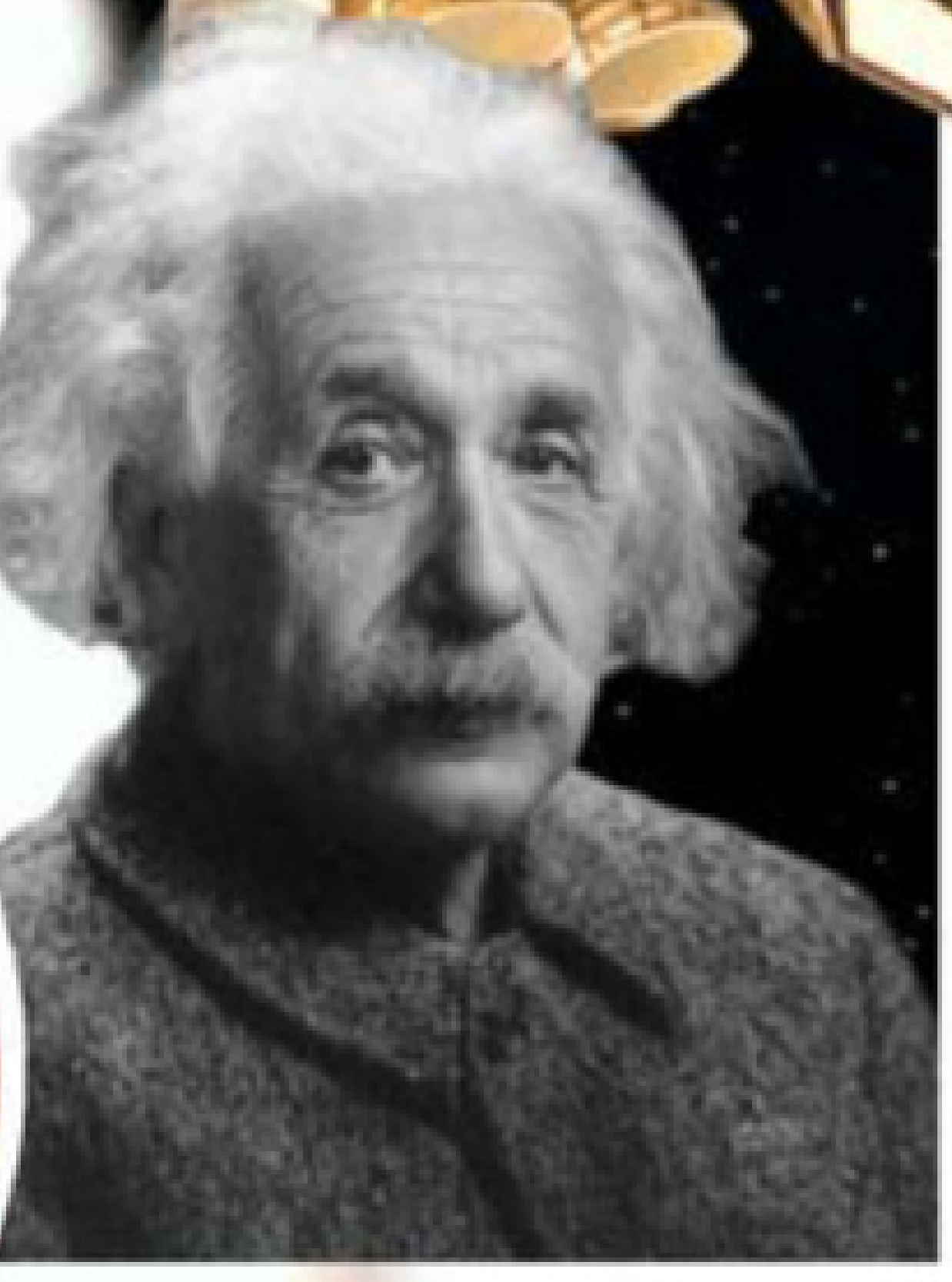

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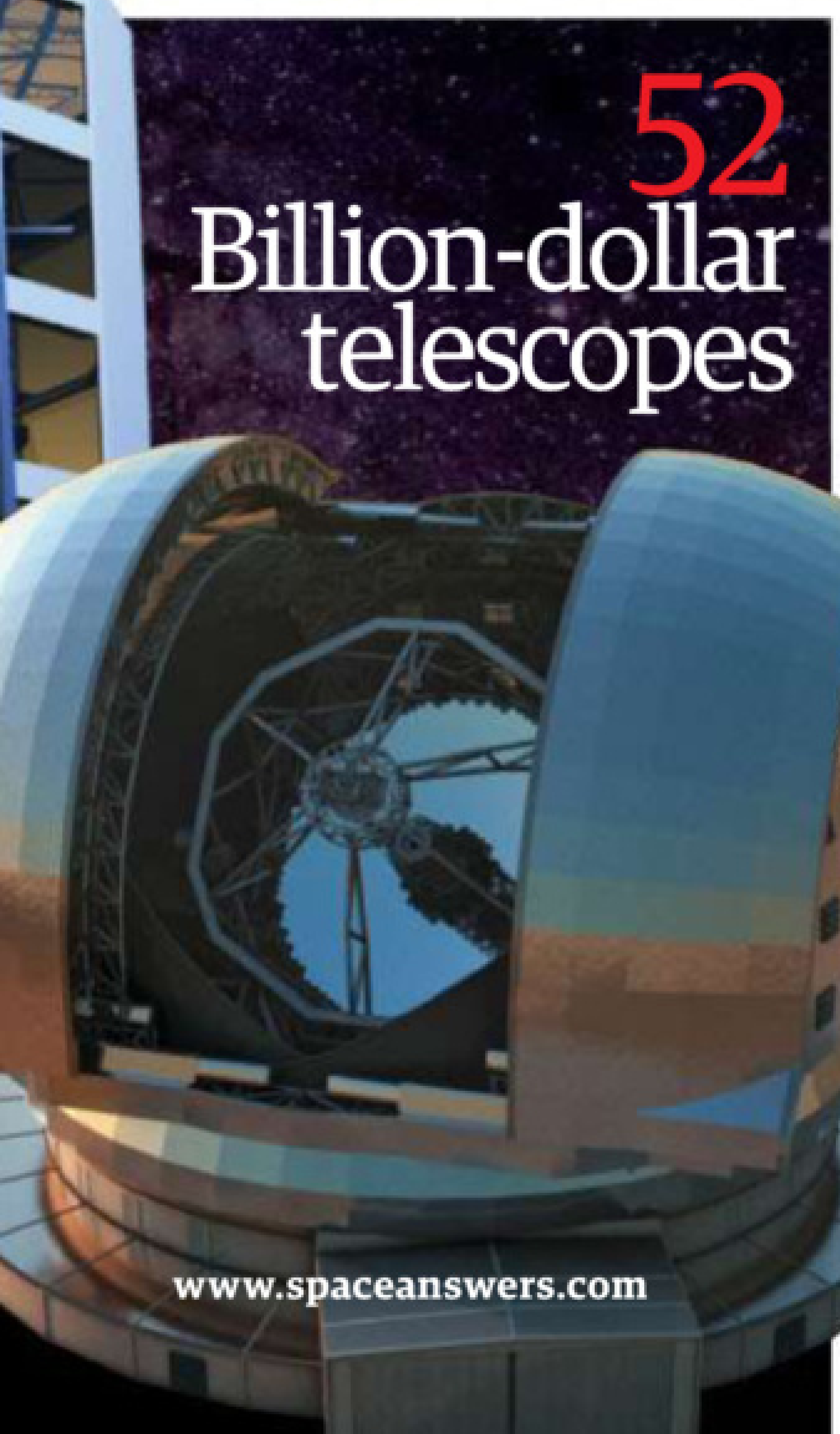

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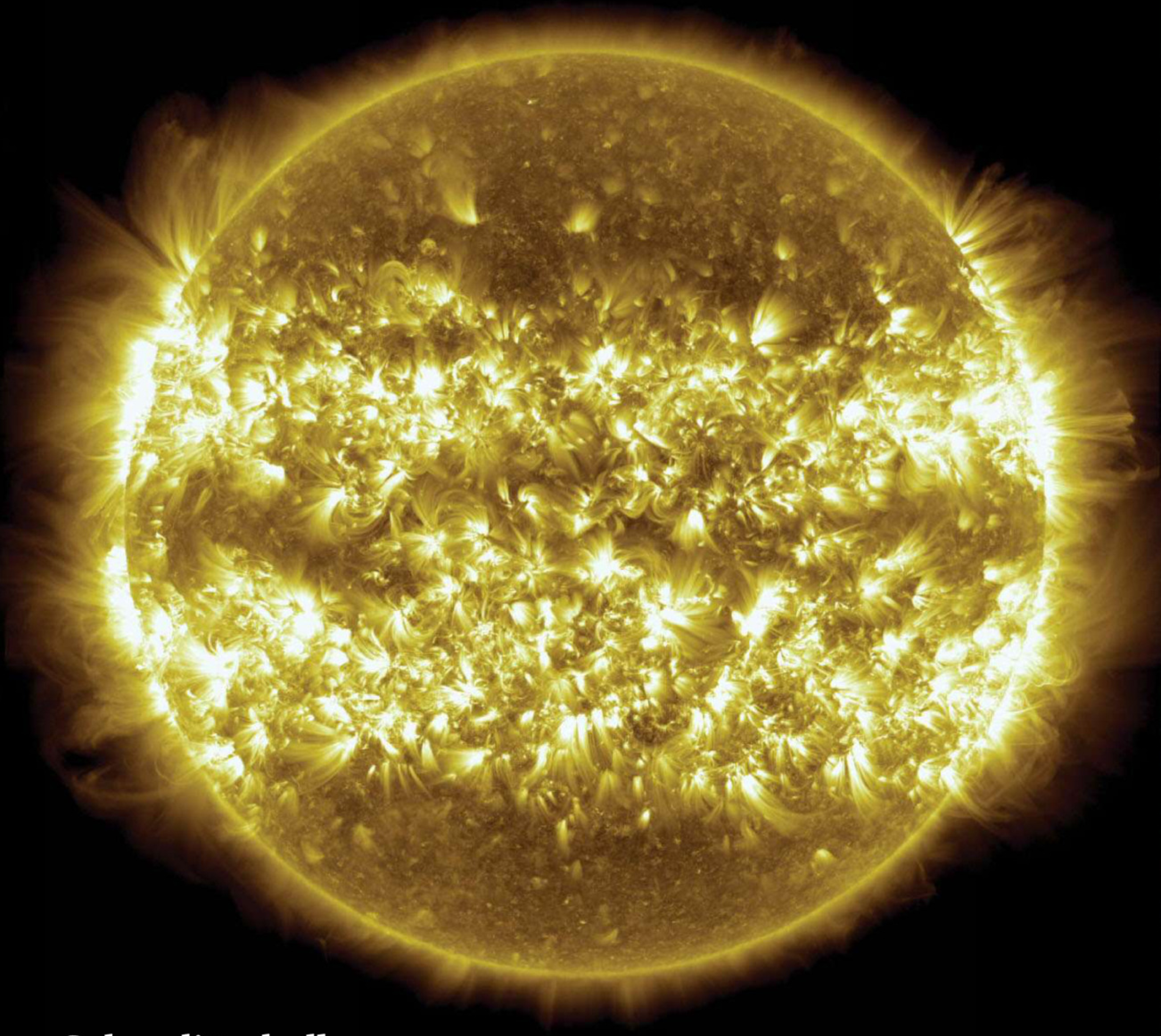
LAUNCH PAD

YOUR FIRST CONTACT WITH THE UNIVERSE

Colourful neighbour

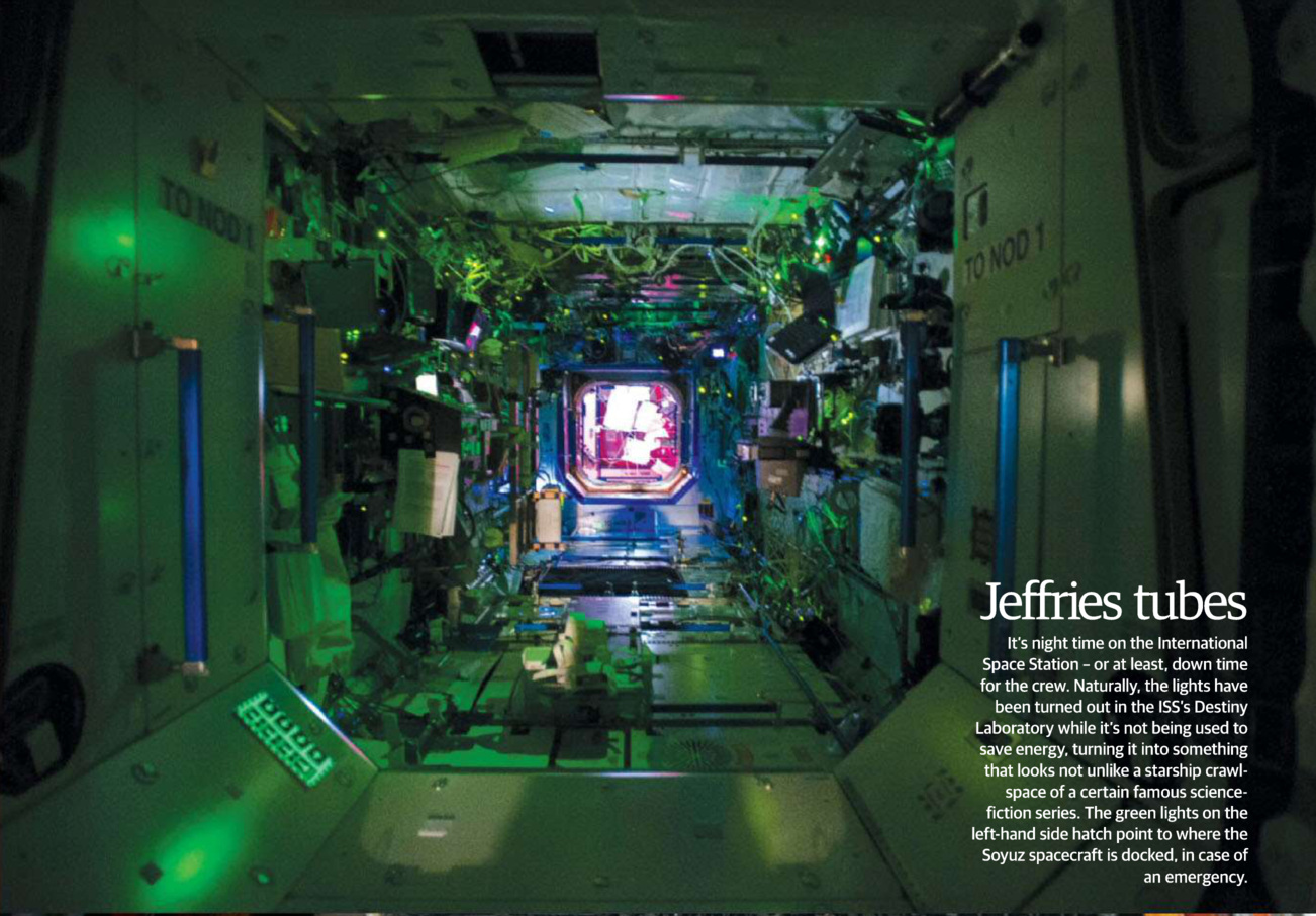
Subject of much terrestrial observation, partly because of its close proximity to the Milky Way, the SMC (Small Magellanic Cloud) certainly makes for spectacular viewing through the eye of a space telescope. A region designated NGC 602 can be found in a part of the SMC known as the Wing, which contains three star clusters of particular interest to astronomers because they mimic the conditions that might have been found in the early universe.

This image is a composite of several taken in X-ray, infrared and optical, by the Chandra X-Ray Observatory, Spitzer and Hubble respectively.



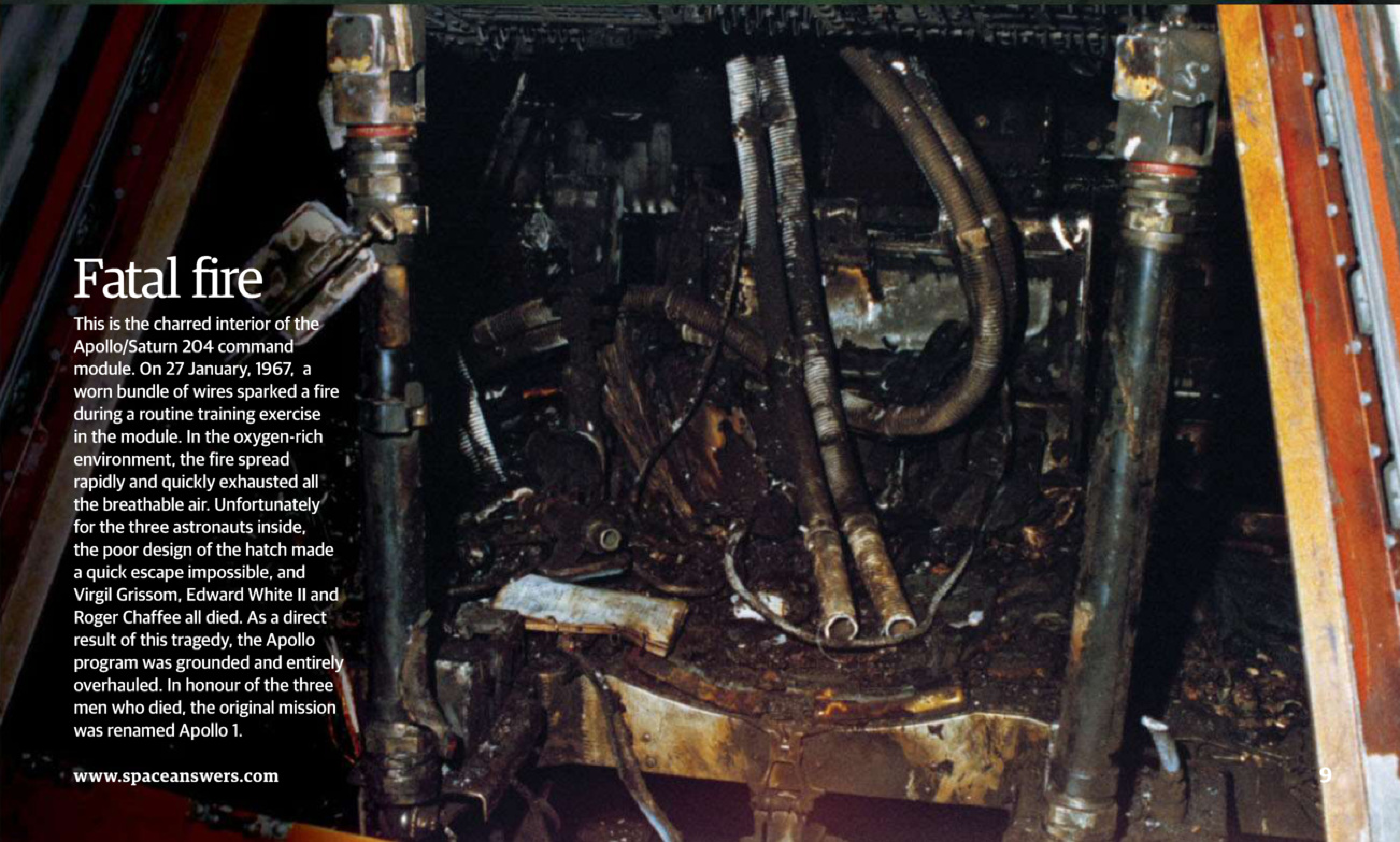
Solar glitterball

This is our Sun, taken by the Solar Dynamics Observatory in a wavelength of 171 Angstroms. It's not a single image of course, if it were, we'd probably be experiencing some pretty major solar-related atmospheric events here on Earth! This is a composite of 25 individual images that span a year, from April 2012 to April 2013. The bright spots of this solar glitterball reveals most active regions of the Sun.



Jeffries tubes

It's night time on the International Space Station – or at least, down time for the crew. Naturally, the lights have been turned out in the ISS's Destiny Laboratory while it's not being used to save energy, turning it into something that looks not unlike a starship crawl-space of a certain famous science-fiction series. The green lights on the left-hand side hatch point to where the Soyuz spacecraft is docked, in case of an emergency.



Fatal fire

This is the charred interior of the Apollo/Saturn 204 command module. On 27 January, 1967, a worn bundle of wires sparked a fire during a routine training exercise in the module. In the oxygen-rich environment, the fire spread rapidly and quickly exhausted all the breathable air. Unfortunately for the three astronauts inside, the poor design of the hatch made a quick escape impossible, and Virgil Grissom, Edward White II and Roger Chaffee all died. As a direct result of this tragedy, the Apollo program was grounded and entirely overhauled. In honour of the three men who died, the original mission was renamed Apollo 1.

Life on Mars

This isn't a million miles from Mars: it's the Mars Desert Research Station in Utah, USA. Technically it's an average of around 225 million kilometres (140 million miles) away from the real deal but, for Earth, it's a pretty close approximation of what conditions would be like for an astronaut on Mars. Here, procedures and equipment can be tested for future missions, and astronauts can have their body and mind's resilience to a stressful environment tested under controlled conditions.

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Inside the Orion nebula, a violent wind of energetic particles tears through a stellar nursery

> "The most likely cause of this anomalous feature in the protostar is an extremely violent wind of energetic particles"

Alien Sun solves meteorite mystery

ESA astronomers discover clues to the chemical origin of Solar System meteorites in a distant Sun-like star

Using data from the Herschel Space Observatory, scientists have been able to unravel a Solar System mystery that has baffled them for some time.

Beryllium-10 is an isotope that's highly unstable and quickly breaks down into other, more-stable forms. It's neither created in the heart of a star nor, like some elements, in the huge energies found in a supernova. Yet evidence of this rare isotope can be readily found in samples of meteorites on Earth.

Scientists surveyed a protostar found in the stellar nursery OMC2 FIR4, a small cluster deep in the Orion nebula, and discovered something unexpected in its chemical composition. The high temperature of -200 degrees Celsius (-328 degrees Fahrenheit) had created a much smaller proportion of what scientists refer to as chemical species: two compounds, one based one nitrogen and the other on carbon and oxygen. This could have been explained by temperatures approaching the absolute chill of deep space, but protostars in a warm environment should not exhibit these compounds.

It's thought the most likely cause of this anomalous feature in the protostar is a violent wind of energetic particles that's being released by one of it's younger siblings. The particles in this wind break apart both chemical species, which keeps them in similarly low proportions.

The protostar in question is in a stage of development that's analogous with the stage our own Sun would have been in 4.5 billion years ago. It's thought that a similar but extremely powerful wind full of energetic particles could have blown through an embryonic Solar System at the time. These particles would have collided with heavier elements, such as oxygen, forming the rare element beryllium-10. What would have been a dense cloud of protoplanetary material coalesced shortly after (relatively speaking), forming the beryllium-10-bearing rocks that would go on to become meteorites.

This is a perfect example of how astronomers and planetary scientists are often able to solve some of the mysteries of our Solar System's formation, not just by examining objects within the sphere of our Sun's influence, but by looking at star systems that are currently like our own was, billions of years ago.

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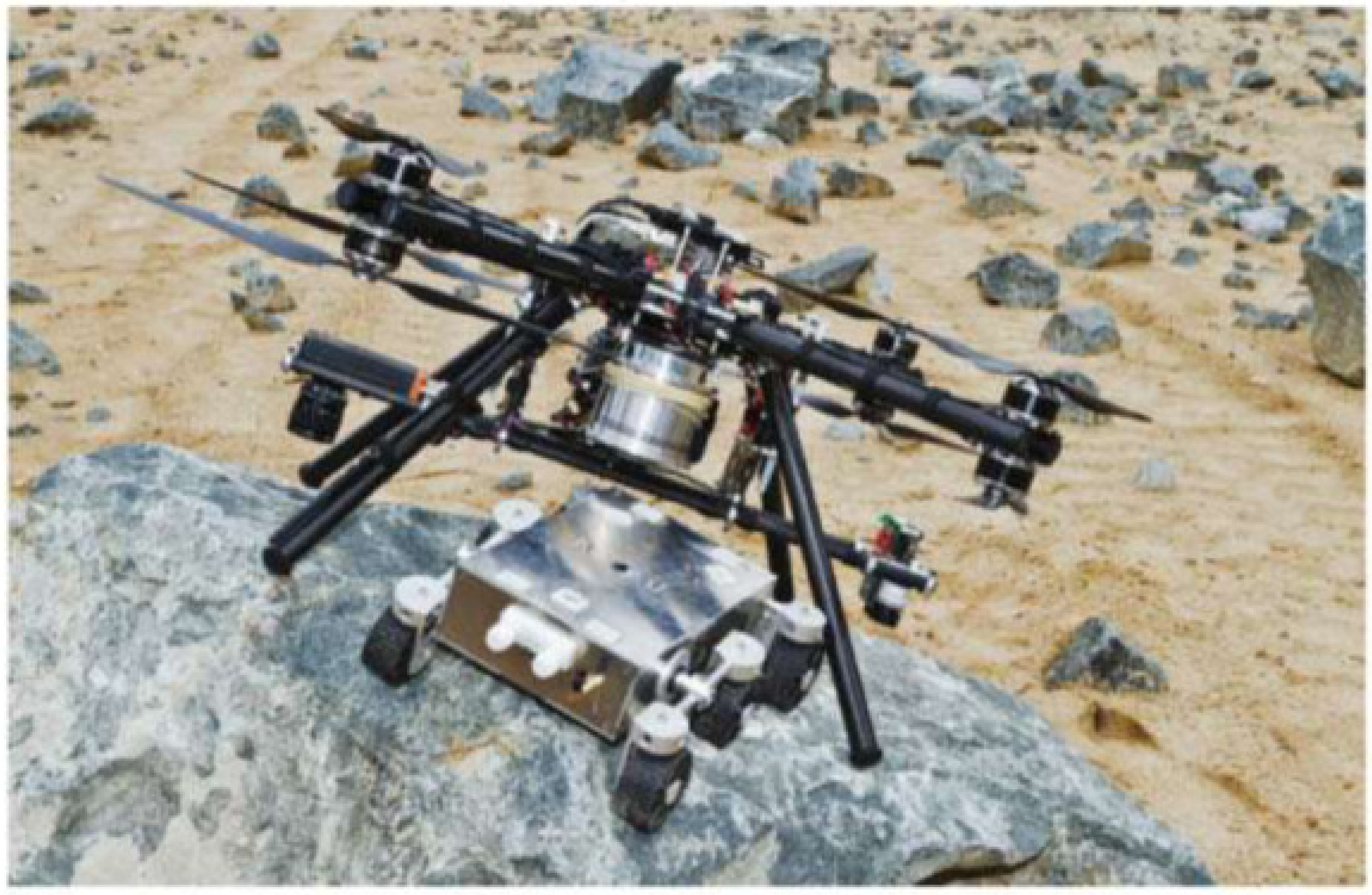
Planetary dropship lands rover safely

The European Space Agency's new quadcopter proves its potential as the next Mars landing craft



"The team has proved the concept, so Dropter can be further developed for Mars"

The ESA's Space Technology Advancements by Resourceful Targeted and Innovative Groups of Experts and Researchers (StarTiger) project, featuring the Dropter, has proved that it's capable of landing a rover on a Mars-like surface.

The StarTiger team was challenged to develop a precision lander to be effectively a technological step beyond the Skycrane that dropped NASA's Curiosity rover onto Mars. It took the team eight months to develop the craft, its navigation and hazard-detection systems.

On the day, the quadcopter first flew to a height of 17 metres (56 feet) before dropping to a ten-metre (33-foot) altitude over a spot it had identified as a safe landing site. Here the quadcopter began to lower the rover on a bridle, using a laser range-finder to navigate until it had safely touched down, then climbing higher again.

The test site itself is based at Airbus Trauen in northern Germany, and is a 1,600-square-metre (17,222-square-foot) re-creation of a typical Martian landscape, strewn with rock hazards, gullies and uneven ground.

There's far to go before the technology can get the green light for use on missions to other planets, but the team has proved the concept, so Dropter can be further developed for Mars or other targets.

StarTiger brings space engineering experts together and challenges them to solve a complex problem within a limited time. ■

For full articles: **www.spaceanswers.com**

Big Dipper hotspot found

A Utah-based observatory has discovered a hotspot for cosmic rays below the Big Dipper. The high-energy rays are disproportionately numerous, and astronomers think the source might be a blazar or a gamma-ray burst from a distant supernova.

ISS super-food test takes off

Spirulina, the super-nutritious algae, is to be sent to the ISS to test its potential as space food. The algae is not only rich in nutrients, but grows quickly and converts carbon into oxygen, so could be used to help do away with resupply missions in future.

Dying galaxy discovered

Astronomers have found a far-flung galaxy over 12 billion light years away that's effectively dying. ALESS65 is one of less than 20 known distant galaxies to contain carbon monoxide. This gas plays a vital role in the life cycle of stars, but ALESS65 is nearly dry.

Rosetta comet is very sweaty

67P/Churyumov-Gerasimenko, the comet that the Rosetta spacecraft is targeting, is releasing around two glasses of water into space every second. This outgassing is streaming away from the comet to form its coma and has been detected much earlier than the Rosetta team expected.

Discover How It Works Illustrated

From the makers of How It Works: a fun and accessible magazine for young readers

The exciting first issue of **How It Works Illustrated** presents a total history of our planet

With fun, easy-to-understand explanations and wonderful artwork to amaze the eye, **How It Works Illustrated** is everything kids love about learning in one monthly manual-sized magazine. Each issue is dedicated to explaining all you need to know about one fascinating topic, from ancient Rome to space exploration and beyond.

Especially designed for younger readers, **How It Works Illustrated** is packed with interesting and engaging stories about the world around us, along with mind-blowing puzzles, challenges and quizzes to stimulate young minds.

In issue one, **How It Works Illustrated** charts the complete history of the world, from the first spark of the Big Bang to the present day. You can discover how big the dinosaurs were, get to know the Vikings, as well as learn how we landed on the Moon. It's an ideal reference for parents and children alike, with hundreds of facts on vital school curriculum topics to nourish enquiring minds.

Explore and discover the world we live in and beyond with the first issue of **How It Works Illustrated**, the new science magazine for younger readers, on sale from newsagents and supermarkets from 31 July. ■

Robonaut's development resulted in numerous spin-off ideas that couldn't be implemented at the time

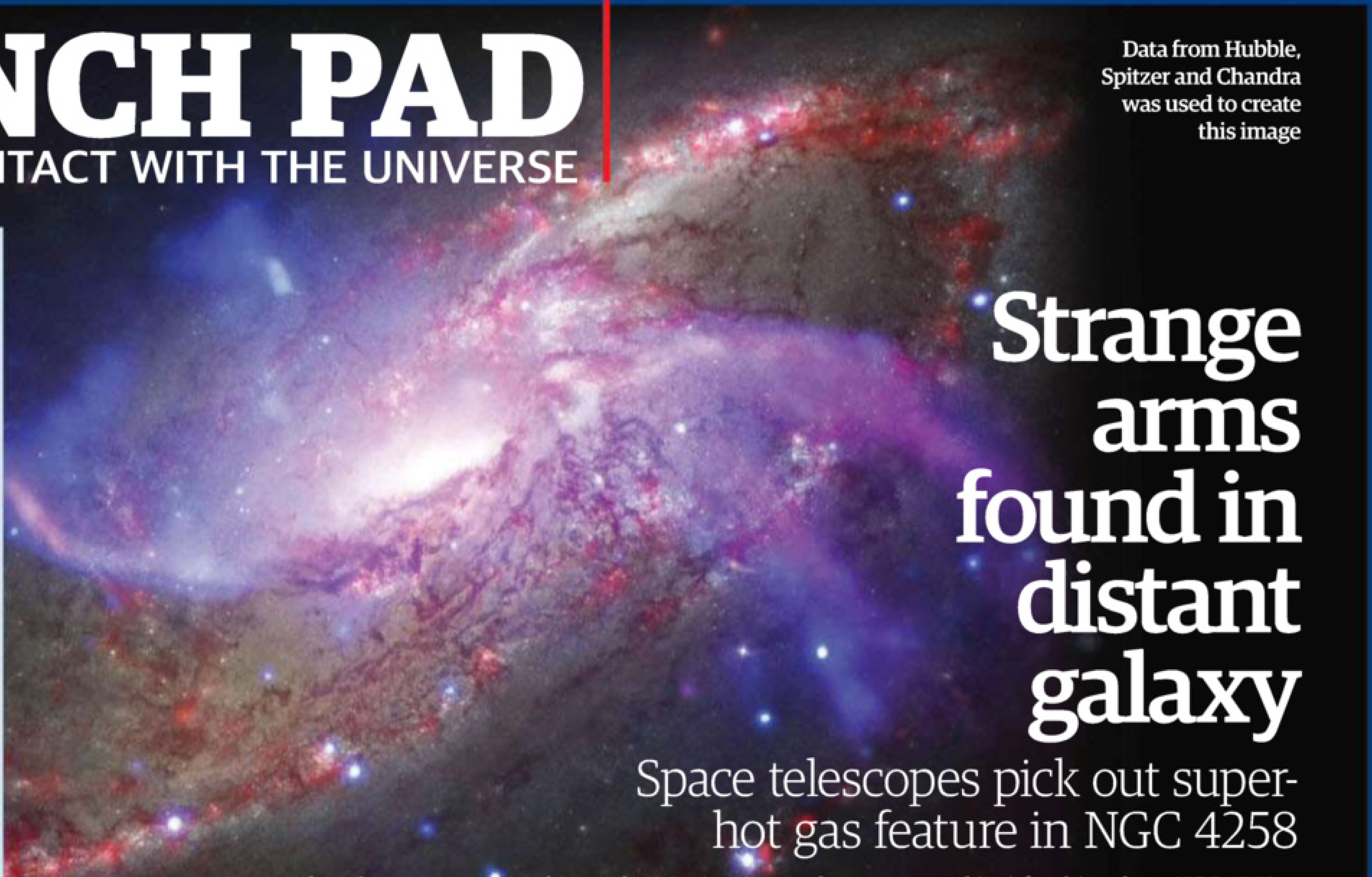
Roboglove assists spacewalks

Robonaut, NASA's humanoid robot aboard the International Space Station, has been helping astronauts out by taking care of difficult, messy and repetitive tasks since its installation in February 2011. Engineers are now developing spin-off robotic technologies to assist humans in other ways.

One of these is the Roboglove, a glove with flexible tendons that can measure the application of the wearer's grasping force and help them, by assisting or resisting any movement. Hand strength is a major issue in any EVA (extra-vehicular activity - such as a spacewalk), as suit pressurisation can act like a balloon in your hand. This requires extra effort for every movement, fatiguing the astronaut and potentially injuring them.

In turn, this technology could have medical applications on Earth, for patients whose hands have been restricted by disease or injury. It could also be implemented in industry, where both precision and strength is required.

Another spin-off technology from Robonaut is telemedicine: although there has been no need for an emergency medical procedure on the ISS to date, in the future doctors may be able to perform one remotely. Under the supervision of a doctor, operators might be able to control Robonaut to conduct basic medical procedures, transferring the doctor's skill from Earth to space. In an emergency situation, this could save an astronaut's life.



Data from Hubble, Spitzer and Chandra was used to create this image

Strange arms found in distant galaxy

Space telescopes pick out super-hot gas feature in NGC 4258

A new composite image of a galaxy 23 million light years from Earth has revealed its anomalous arms. NGC 4258 is a spiral galaxy like our own Milky Way, but with some key differences. One of them is an extra pair of arms that aren't aligned with the plane of the galaxy and instead intersect either side of it.

The reason for these strange galactic limbs is another anomalous feature of NGC 4258: a gigantic black hole at its core. This is ten times bigger than Sagittarius A*, the supermassive black hole at the centre of our galaxy.

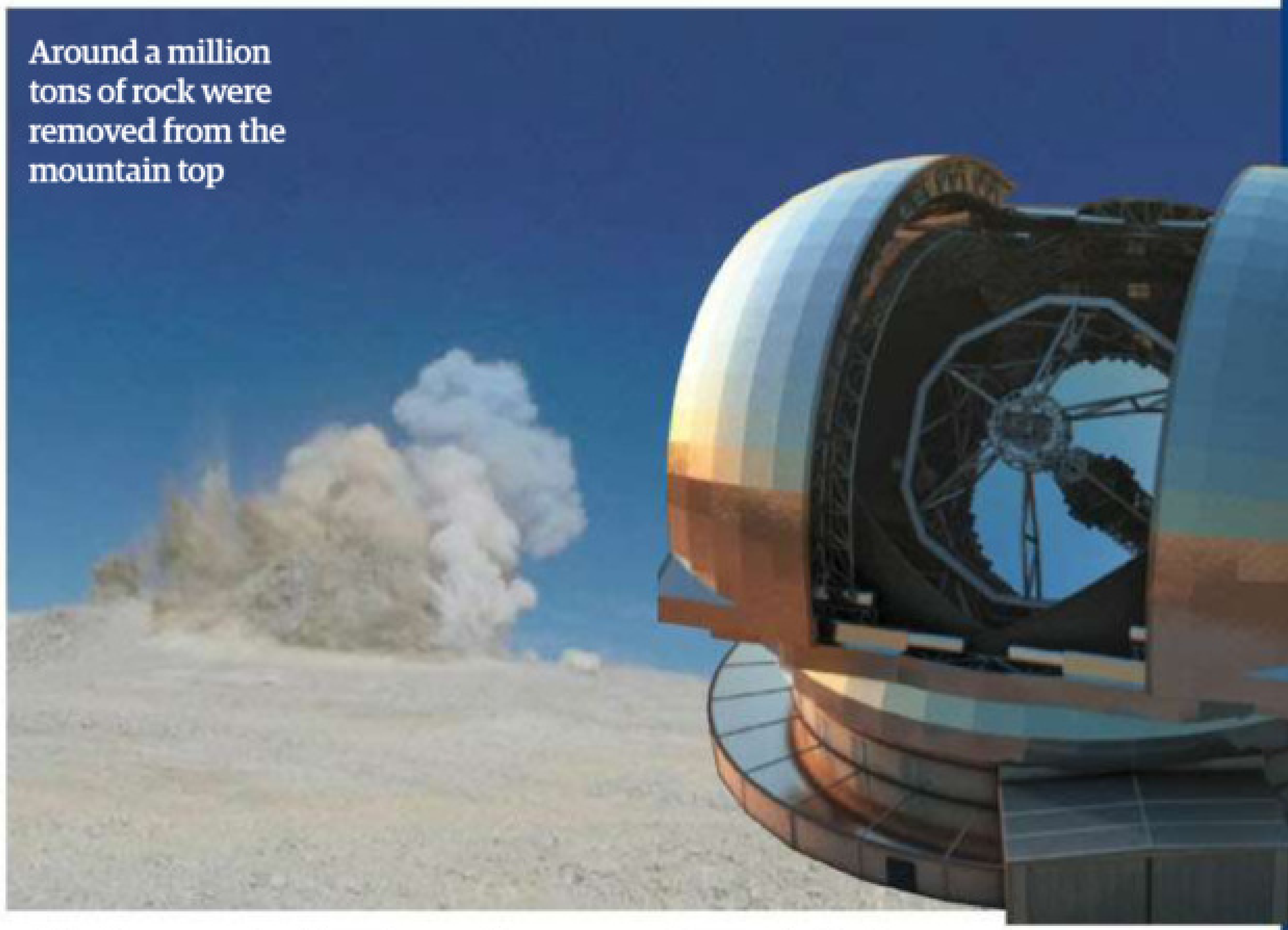
The radio data in the image (in purple) shows the black hole creating jets of high-energy particles that strike the main galactic disk and create shock waves. This super-heats the gas (mostly hydrogen) to millions of degrees and is then jetted out into an area just outside the disk.

Ultimately this activity will prove fatal in the short-term (cosmologically speaking) for this galaxy. NGC 4258 has already ejected most of its gas and the last of it will leave within the next 300 million years. Without this gas, no new stars can form and NGC 4258 will effectively be a dead galaxy.

Data from NASA's Spitzer, Hubble and Chandra space observatories was verified by the ESA's Herschel telescope to estimate how much gas remains. The galaxy's close proximity to Earth has enabled experts to study how its black hole is affecting it.

Mountain blown up for super telescope

Summit levelling begins on the future high-altitude site of the ESO's E-ELT



Around a million tons of rock were removed from the mountain top

A portion of the (formerly) 3,064-metre (10,052-foot) summit of Cerro Armazones in Chile has been blown up in preparation of the future site for the ESO's European Extremely Large Telescope. A million tons, or 220,000 cubic metres (7.8 million cubic feet) of rock were shifted in a controlled explosion that lowered the peak by around 40 metres (131 feet).

The blast was the first of several steps to flatten the mountain top, while others will include paving a road to the new telescope site and laying a service trench. Work started earlier this year and will take a further 16 months to be finished some time in late 2015. The telescope itself will take nearly a decade longer to complete and is expected to be operational by 2024.

Currently the Cerro Armazones mountain is home to several other telescopes at the Cerro Armazones Observatory, 20 kilometres (12.4 miles) away from the ESO's Paranal Observatory. The E-ELT will be one of the biggest telescopes in the world, at 39 metres (128 feet), and you can read more about it and what it will be able to see on page 52.

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All About…

R136a1

the impossible stellar giant

At the heart of a brilliant star cluster, 165,000 light years from Earth, lies the heaviest star in the known universe – a rare type of blue hypergiant with a mass of 265 Suns

Written by Giles Sparrow

Just how big can a star get? Like many questions in astronomy, the answer depends on how exactly you define your terms. The biggest stars in terms of diameter are red giants and red supergiants that swell to enormous sizes as their lives come to an end. As they begin to exhaust their fuel and go through internal changes, these stars also brighten enormously, swelling in size as their surfaces become cooler and redder. A star like the Sun may swell to a diameter large enough to engulf Earth, while heavier supergiants like Betelgeuse (with up to 20 times the mass of the Sun) may be up to five times larger – reaching Jupiter's orbit in the Solar System.

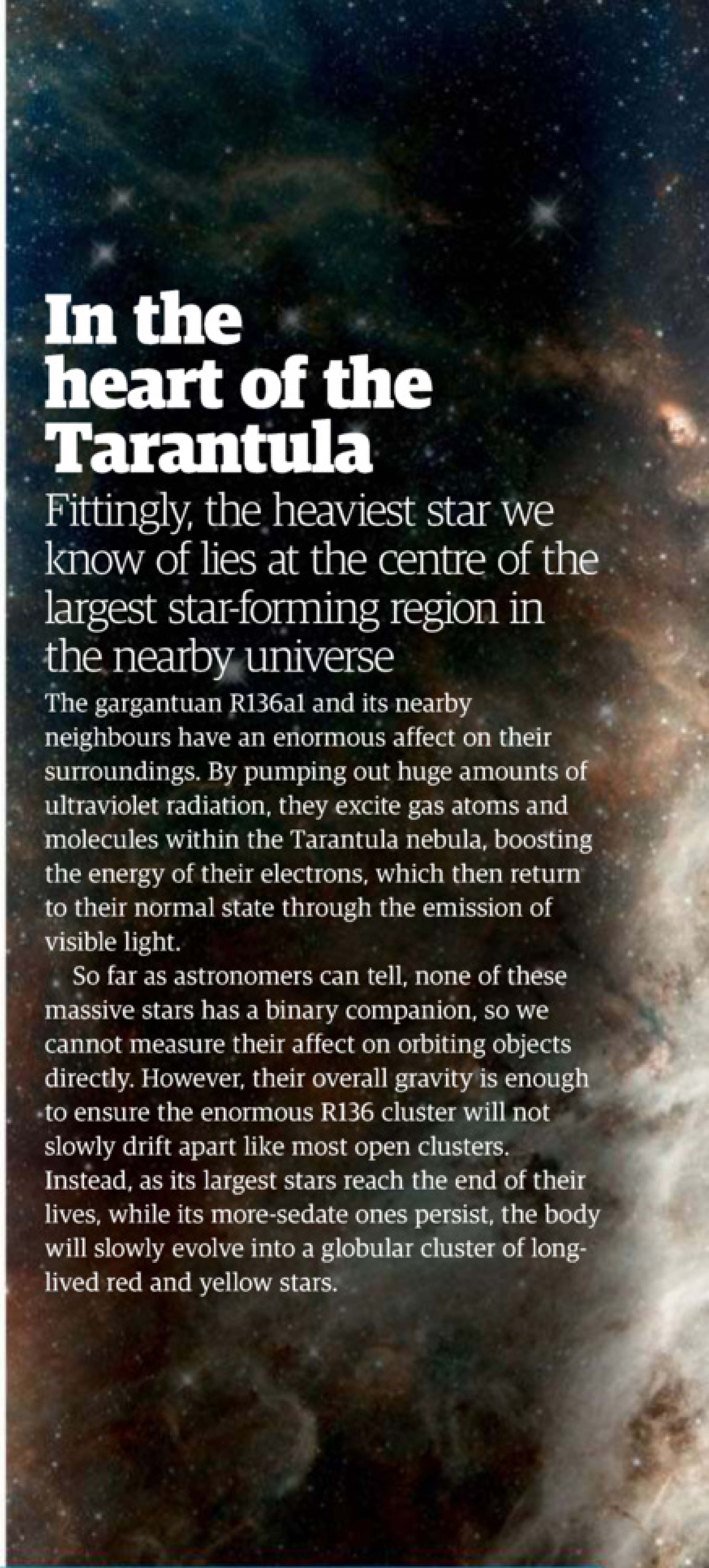
If by defining the biggest star you simply mean the most massive, then the answer to the question is very different – the most monstrous stars of all are hypergiants, holding many times the mass of the Sun. Perhaps surprisingly, a star of this kind will never grow to the impressive size of its red cousins – its gravity is so powerful that it holds it together against the forces that inflate lighter stars, ensuring it will remain incandescently hot throughout its short but bright lifespan. The most massive of all these stellar behemoths was discovered in a neighbouring galaxy of the Milky Way in 2010 – a hypergiant star with about 265 times the mass of the Sun, catalogued as R136a1.

Fittingly, this stellar bruiser is a resident of the largest star-forming nebula in our Local Group – the Tarantula nebula in the Large Magellanic Cloud (LMC). Looking at first glance like a detached portion of the Milky Way in far southern skies, the LMC is one of the largest and brightest of several satellite galaxies trapped in billion-year orbits around the Milky Way. Huge tidal forces are compressing its copious reserves of gas and dust to trigger the birth of new stars at a much faster rate than in our own galaxy, giving rise to the Tarantula nebula.

Within this region, some 650 light years across, radiation from newborn stars excites the surrounding gas to glow intensely at naked-eye wavelengths. The Tarantula is famously so large and luminous that, if it were transplanted to the location of the famous Orion nebula, just 1,350 light years away, it would cover an area several times that of the full Moon and be bright enough to cast shadows at night.

Inside the nebula, stars proceed to be born in waves as huge knots of gas condense in a runaway chain reaction. Radiation from the first newborn stars in any given region creates shockwaves that ripple through the surrounding nebulosity and further trigger its collapse into more stars. At the same time, the pressure of radiation blows away any material left unclaimed by other nascent stars. This produces distinctive caverns of star-formation regions with newborn open star clusters at their centre.

The Tarantula has already gone through this process at least twice, producing two generations of young stars. The older group, known as Hodge 301, is about 25 million years old and now lies about 150 light years from the centre of the nebula. It contains a couple of hundred stars, about 40 of which have already exploded as supernovas at the end of their lives (indicating that they were the cluster's most massive stars and therefore aged at the fastest rate). The younger R136 cluster at the very centre of the nebula, meanwhile, is thought to be just 2 million years old. This means that even its heaviest stars have not yet had time to age and die and it's this youth that makes R136 a rich hunting ground for astronomers in search of the heaviest stars in the known universe. ■



In the heart of the Tarantula

Fittingly, the heaviest star we know of lies at the centre of the largest star-forming region in the nearby universe

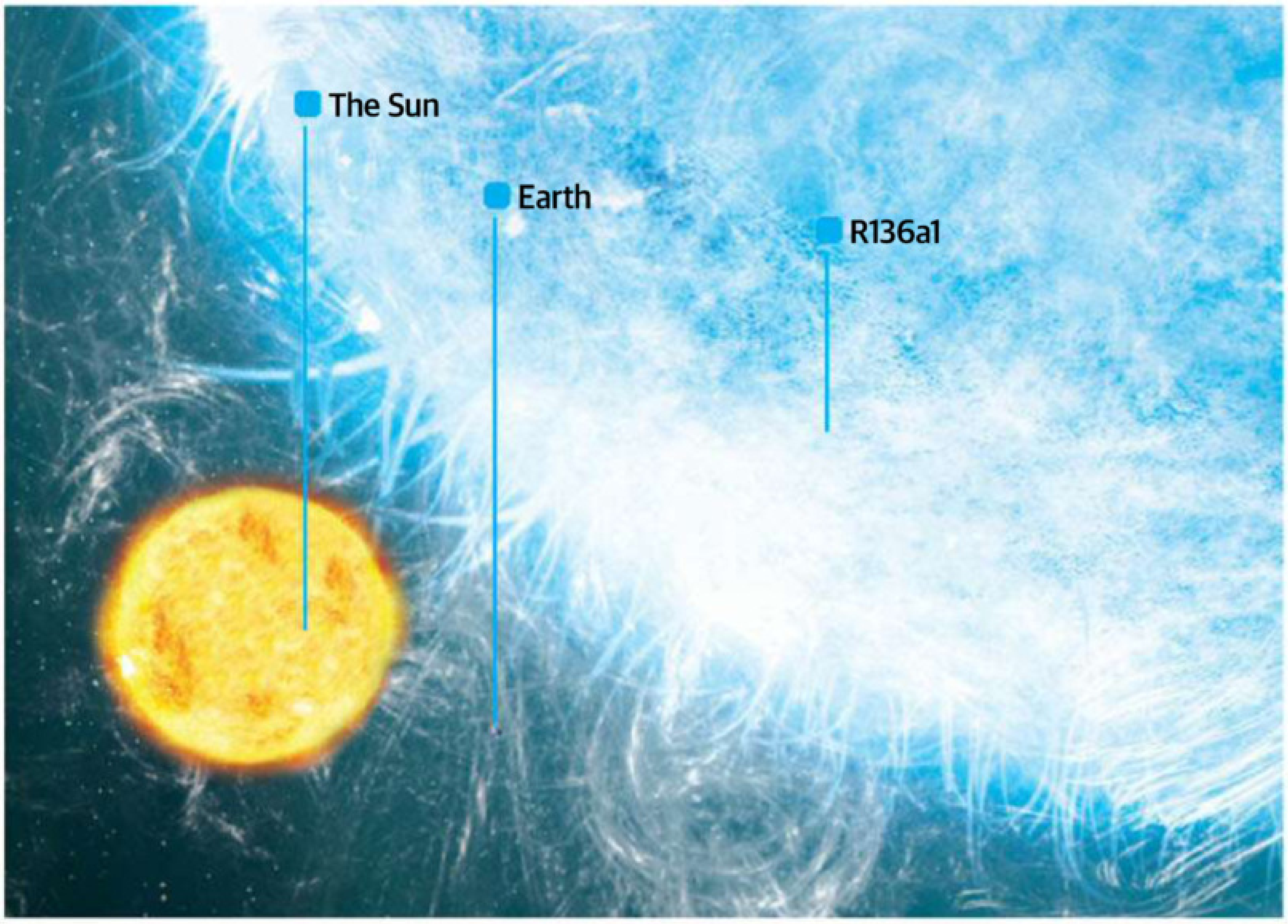
The gargantuan R136a1 and its nearby neighbours have an enormous affect on their surroundings. By pumping out huge amounts of ultraviolet radiation, they excite gas atoms and molecules within the Tarantula nebula, boosting the energy of their electrons, which then return to their normal state through the emission of visible light.

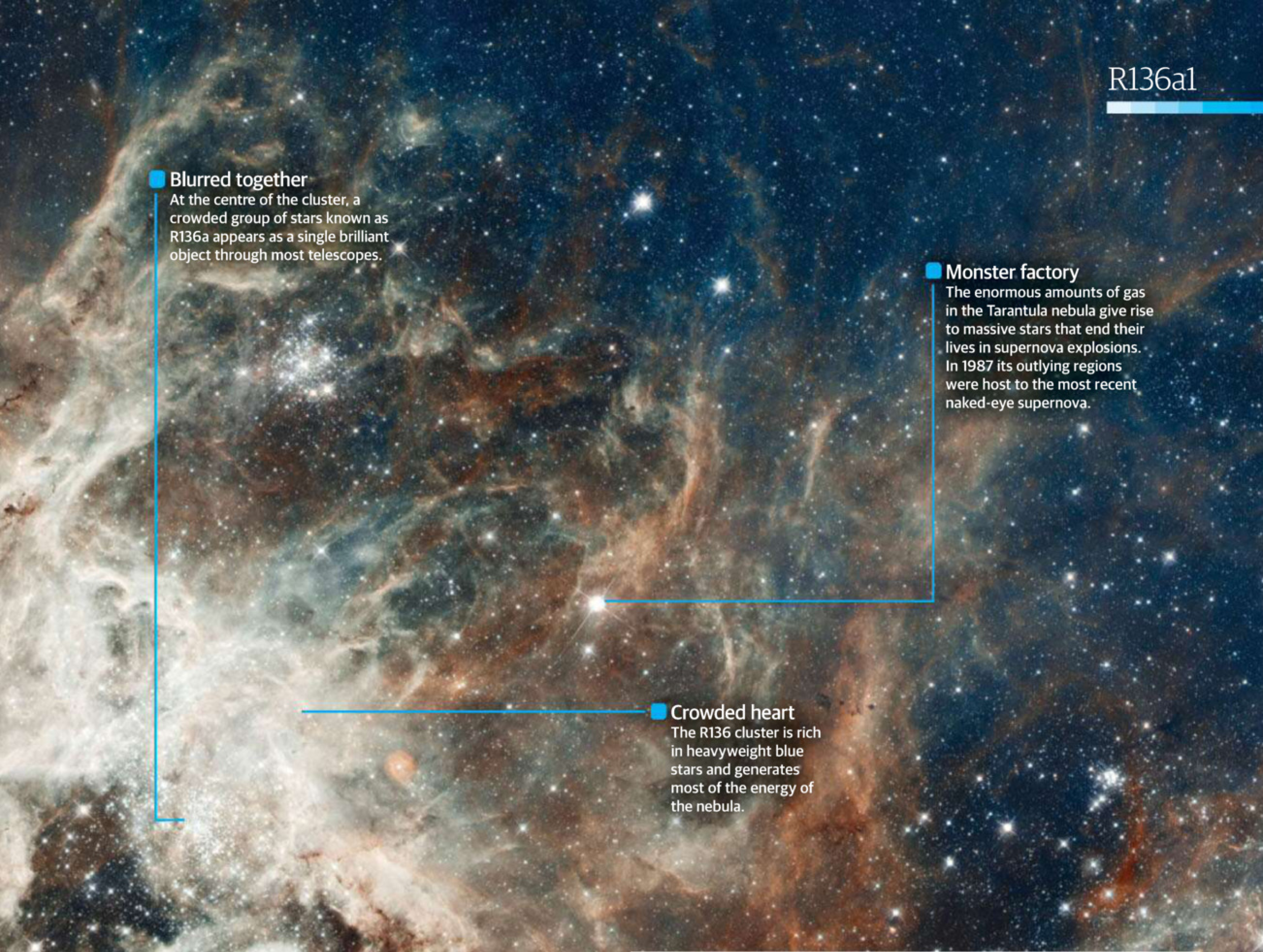
So far as astronomers can tell, none of these massive stars has a binary companion, so we cannot measure their affect on orbiting objects directly. However, their overall gravity is enough to ensure the enormous R136 cluster will not slowly drift apart like most open clusters. Instead, as its largest stars reach the end of their lives, while its more-sedate ones persist, the body will slowly evolve into a globular cluster of long-lived red and yellow stars.

What if?

If R136a1 were as close as our Sun, it would outshine it by as much as the Sun outshines the Moon

Although its powerful gravity prevents it from growing quite as large as some red supergiants, R136a1 is still a mightily impressive star. If it took the Sun's place at the heart of our Solar System, it would stretch halfway to the orbit of Mercury and appear 35 times larger than the Sun in our skies. Its powerful gravity, meanwhile, would require the planets to orbit much faster in order to maintain their current locations – Earth would have to move along its orbit at roughly 500 kilometres (311 miles) per second – over 16 times its current average speed. More dramatically, however, the searing radiation from our new star would strip away our planet's atmosphere and instantly boil its oceans off into space, making life impossible.





Blurred together
At the centre of the cluster, a crowded group of stars known as R136a appears as a single brilliant object through most telescopes.

Monster factory
The enormous amounts of gas in the Tarantula nebula give rise to massive stars that end their lives in supernova explosions. In 1987 its outlying regions were host to the most recent naked-eye supernova.

Crowded heart
The R136 cluster is rich in heavyweight blue stars and generates most of the energy of the nebula.

A stunning Hubble Space Telescope image offers a view of the R136 region, home to the heaviest known stars. As well as R136a1 (265 solar masses), the cluster also contains R136a2 (195 solar masses)

Inside the giant

A high mass and compact size turns R136a1 into a super-hot stellar behemoth

With a mass of 265 Suns, R136a1 is so huge that astronomers were shocked by its discovery – it's almost twice as massive as any known star in the Milky Way. Two of its close neighbours in the R136 cluster also beat the previous record-holder – the 150-solar-mass Peony star.

R136a1 is surprising because it comes close to breaking the rules of stellar physics. For more than half a century we've understood that the heavier a star is, the brighter it shines during its main-sequence lifetime. This is the stable period of its life where it generates energy by nuclear fusion of hydrogen to form helium in its core. This mass-luminosity relationship is driven by the two different processes involved in fusion. Even though R136a1 has much more hydrogen fuel than the Sun, it's squandering it much more quickly and it will reach the end of its life after maybe 5 million years.

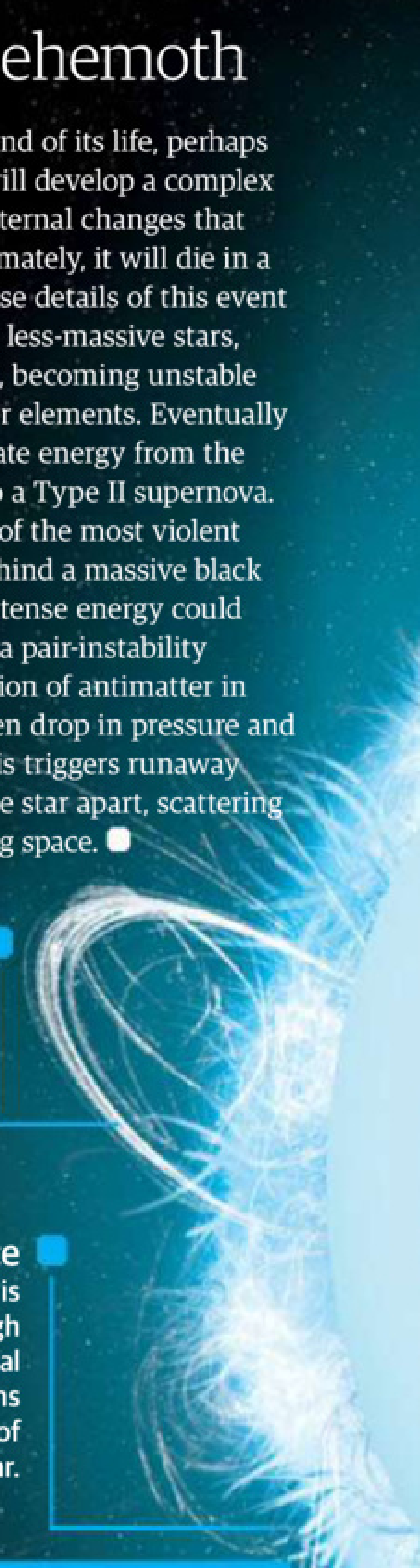
Astronomers believe this relationship puts a natural upper limit on the stellar mass – a star with the mass of R136a1 should, they thought, generate such fierce radiation that it would simply blow itself apart even as it is formed. However, this giant has challenged conventional stellar theories, causing scientists to change the rules – it simply shouldn't exist within the previous laws. Instead, it now seems that stellar behemoths up to perhaps 300 solar masses are capable of holding themselves together through their powerful gravity, which keeps the outer layers close to the star rather than forcing them to balloon outwards.

However, this makes radical changes on the other properties of such hypergiant stars. The amount of energy blasting its way out through relatively small surface areas heats them to searing temperatures and this in turn creates a powerful stellar wind as hot gas from the surface blows away into space. This effect, perhaps a billion times more powerful than our own Sun's solar wind, enables stars like R136a1 to shed an entire solar mass of material every few hundred thousand years. This exposes more of its hot internal layers at the surface, which only serves to strengthen the wind still further.

The result is an extreme Wolf-Rayet star – an object that may have lost more than 50 Suns' worth of its original material, and whose exposed surface exceeds 50,000 degrees Celsius (90,000 degrees Fahrenheit). Although astronomers have not yet obtained information about R136a1's composition from a spectrum of its light, evolutionary models suggest it must be a Wolf-Rayet.

As R136a1 approaches the end of its life, perhaps 2 million years from now, it will develop a complex layered structure thanks to internal changes that enable it to keep shining. Ultimately, it will die in a huge supernova, but the precise details of this event are still uncertain. It may, like less-massive stars, keep shining to the bitter end, becoming unstable as it burns heavier and heavier elements. Eventually the doomed attempt to generate energy from the fusion of iron would tip it into a Type II supernova. This cataclysm would be one of the most violent ever seen and would leave behind a massive black hole. Alternatively, R136a1's intense energy could trigger a rare event known as a pair-instability supernova, in which the creation of antimatter in the star's core triggers a sudden drop in pressure and a premature core collapse. This triggers runaway nuclear reactions that blow the star apart, scattering its material across surrounding space.

In its last days, R136a1 may become more unstable and prone to violent eruptions as it evolves into a luminous blue variable star similar to Eta Carinae, pictured here


Stellar wind
Fast-moving gas escapes from R136a1's gravity at a tremendous rate, allowing the star to shed many Sun's worth of material over its lifetime.

Incandescent surface
R136a1's surface is incandescently hot – though we say it is blue, the actual combination of its wavelengths creates an overall impression of a white-hot star.

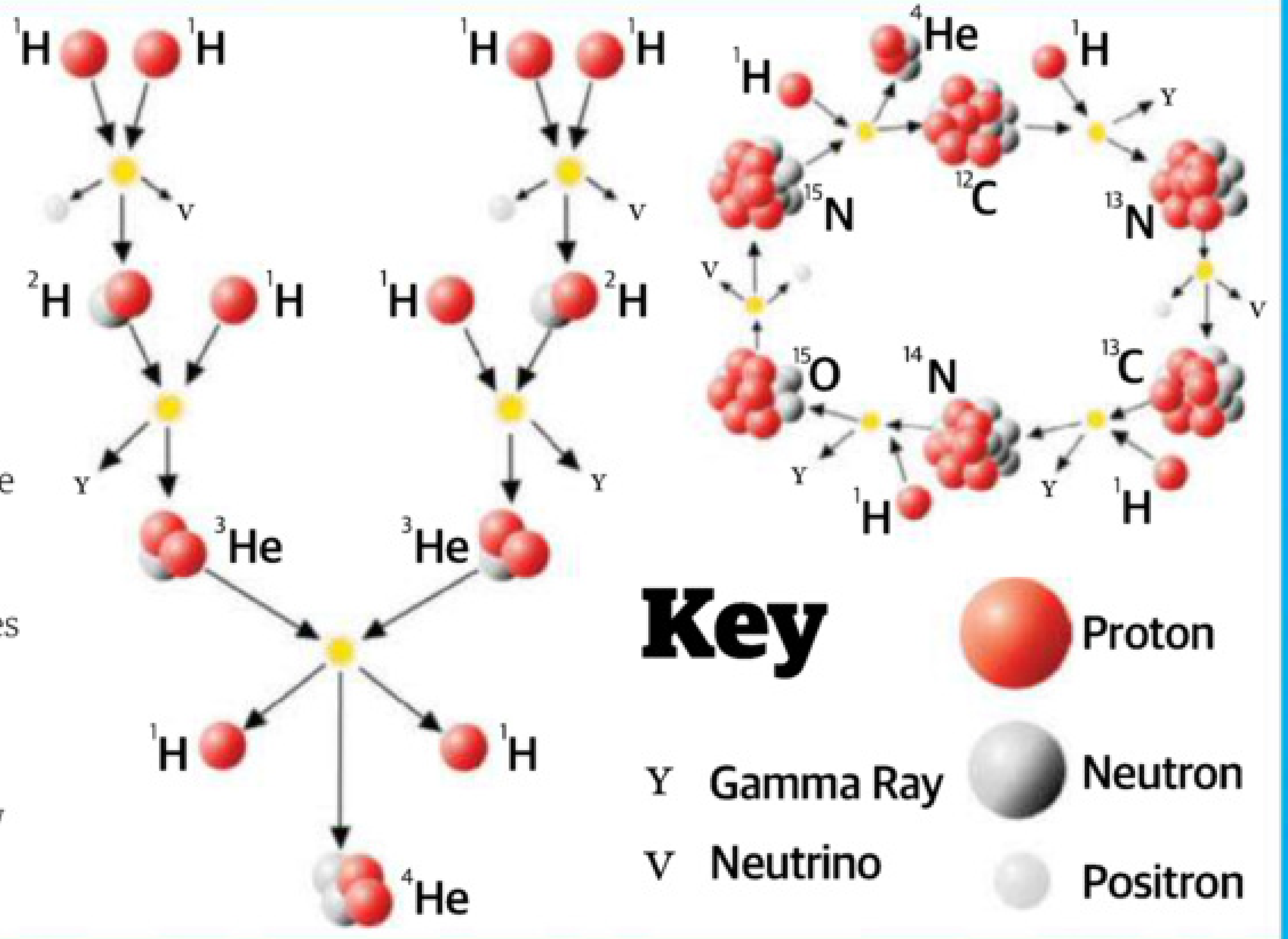
Fusion chains and cycles

Two different types of nuclear fusion generate the energy in low-mass and heavyweight stars

The fundamental power source of all middle-aged, or main-sequence stars is nuclear fusion. This is the joining together of atomic nuclei of hydrogen (the lightest and most abundant element) into those of helium.

Most stars build helium nuclei by a direct fusion of hydrogen nuclei (subatomic particles called protons) to create successively heavier nuclei that then merge to release helium. This proton-to-proton chain reaction takes place relatively slowly, so limits the energy output of stars like the Sun.

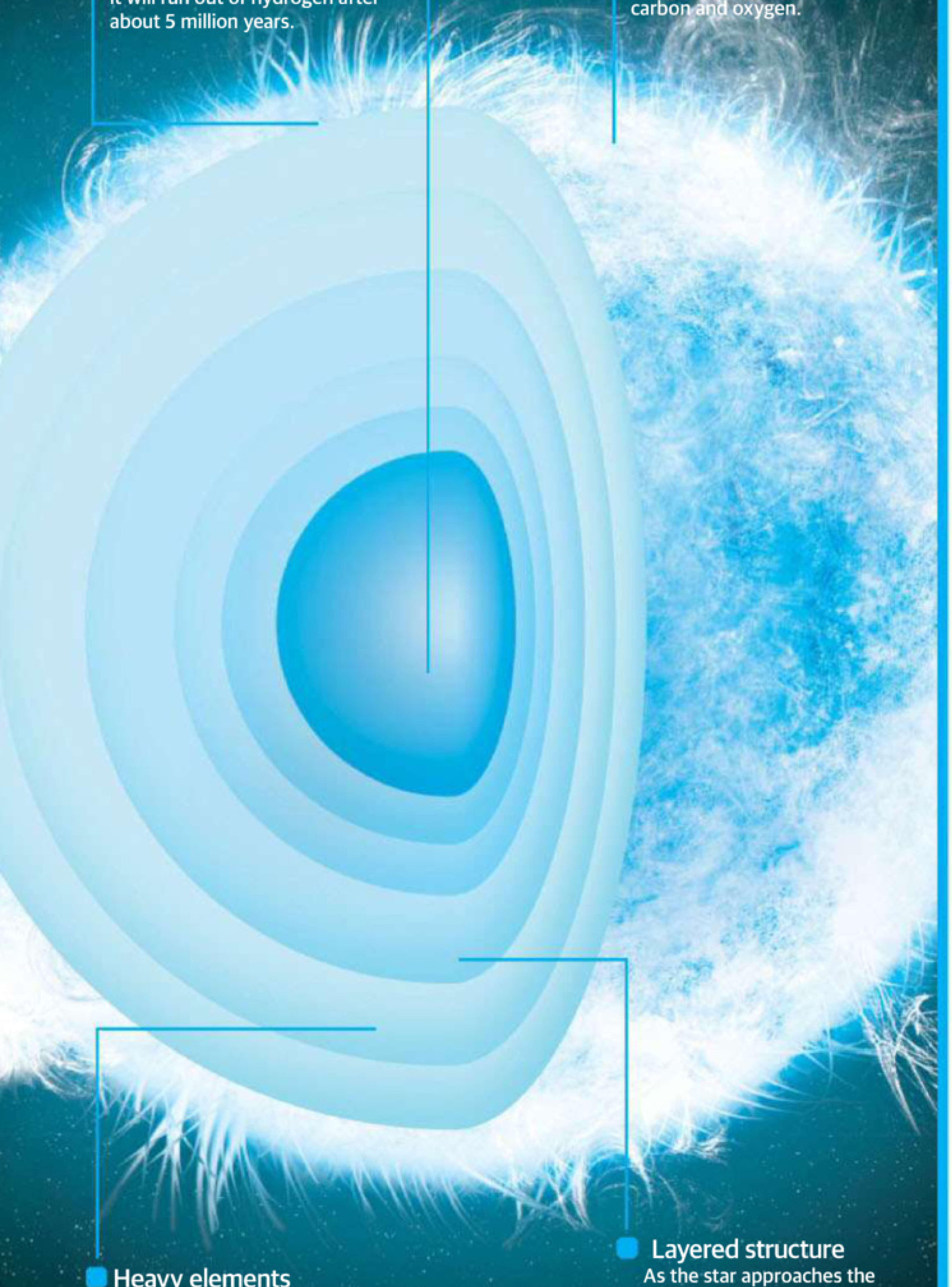
In the hot, high-pressure cores of heavyweight stars, the carbon-nitrogen-oxygen cycle dominates. Here, protons bind with nuclei of carbon, creating nitrogen and oxygen nuclei in turn, before the addition of a further proton breaks the nucleus apart to release helium and unaltered carbon. This CNO cycle operates quicker than the PP chain, enabling massive stars to shine brighter. What's more, it becomes ever more efficient at higher temperatures, which explains how monster stars like R136a1 can pump out millions of times the energy of the Sun.



Time bomb
At the heart of the dying star, a solid core of iron gradually accumulates. Attempts to fuse iron absorb energy rather than generate it, triggering a collapse whose rebound destroys the star in a gargantuan supernova.

Short fuse
Despite its enormous quantities of material, R136a1 burns fuel at such a tremendous rate that it will run out of hydrogen after about 5 million years.

Exposed interior
As the stellar wind blows away the star's outermost layers, more of its hot interior is revealed, enriched with fusion products such as helium, carbon and oxygen.



Heavy elements
In its last moments, R136a1 will have a complex structure. While hydrogen and helium will be near the surface, successive layers of carbon, oxygen, neon, magnesium and silicon fusion will lie at its greater depths.

Layered structure
As the star approaches the end of its life, it will become increasingly unstable, continuing to shine through nuclear fusion of successively heavier elements in shells around its core.

By the numbers

165,000 ly

The estimated distance of the R136a1 from Earth.

8.7 million Suns

R136a1's huge total energy output – much of this is emitted as invisible ultraviolet radiation.

48.7 million km

The approximate diameter of R136a1 is 35 times that of the Sun.

265 solar masses

R136a1's greatest claim to fame – its mass is greater than that of any other known star.

2 million years

R136a1's estimated age – it is probably about halfway through its lifetime.

450,000 Suns

Overall mass of the R136 cluster. This is far more than any known star cluster in the Milky Way.

53,000°C

The monster star's incandescent surface temperature is almost ten times that of the Sun and enough to make it glow blue.

Observing R136a1

Despite its brilliance, this massive star is challenging to observe, thanks largely to its crowded surroundings

Seen across 165,000 light years of space, R136a1's brilliant light dwindles to an apparent magnitude (brightness from Earth) that is well below naked-eye visibility, at 12.3. Nevertheless, it remains within the reach of all but the smallest telescopes – the real problem lies in its proximity to other stars in R136. In the early 1980s astronomers speculated that the central object known as R136a might be a single bright star with the mass of 1,500 Suns, but many doubted that such a monster could exist. They were proved right in 1985 when R136a was confirmed to be a densely packed cluster.

As seen from Earth, the stars R136a1, a2 and a3 are separated by approximately 0.1 and 0.5 seconds of arc (a second of arc is 1/3,600th of a degree or roughly 1/1,800th the diameter of the full Moon). Put another way, resolving the two closest stars is like trying to distinguish between two candles separated by the diameter of a ten pence (or US quarter) coin, over a distance of 28 kilometres (17.4 miles). While this might be a tiny angle in everyday terms, according to optical theory this is the kind of detail that should be resolvable through a telescope with a diameter of a metre (3.3 feet) or more.

The problem lies in Earth's atmosphere, which complicates the theoretical behaviour of light in unpredictable ways. Moving masses of air act like tiny lenses, bending and warping the path of light rays, while blurring and shifting the images seen from the surface. This is the phenomenon that causes stars to flicker and twinkle in the sky, while on long-exposure photographs it causes the images of stars to smear out from points into fuzzy-edged discs. Even at mountain-top altitudes, above most of the atmosphere, it reduces the resolving power of even the largest telescope to about 0.5 seconds of arc, blurring images of R136a and making its individual stars indistinguishable.

In the past decade, astronomers have finally started to overcome this problem using the ingenious technology known as adaptive optics (AO). The principle is simple – adjusting the configuration of the telescope itself to correct for changing atmospheric turbulence – but putting it into practice requires huge amounts of computing power.

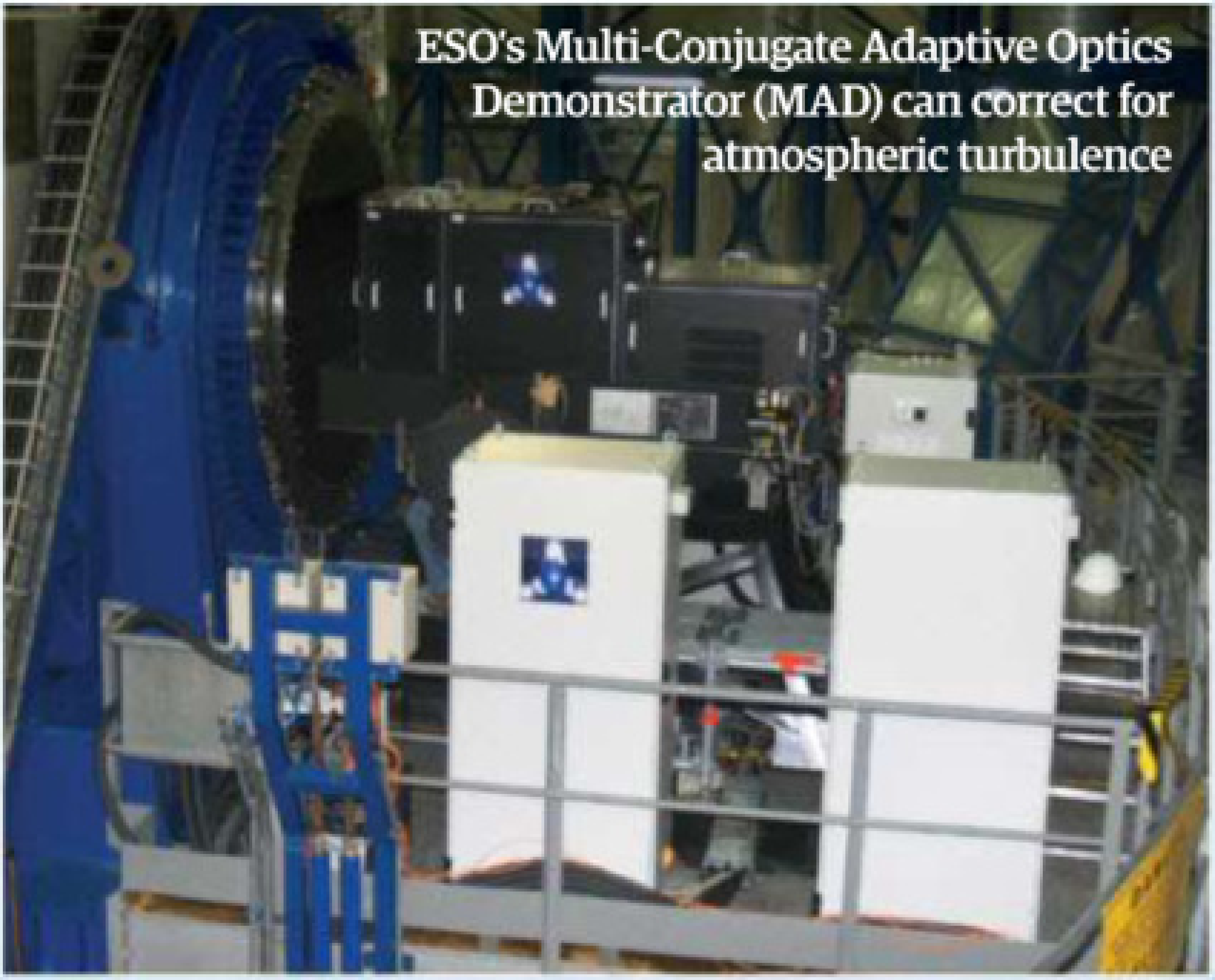
It was the adaptive optics system on the European Southern Observatory's Very Large Telescope that enabled a team of astronomers led by Paul Crowther of the University of Sheffield to produce the first resolved image of the cluster's heart. Based on the brightness of its individual stars, and a comparison with a relatively nearby monster star with better-known properties, the team was able to calculate R136a1's physical properties. They revealed the secrets of what remains (for the moment, at least) the heaviest star in the universe. ■

A glimpse through the VLT

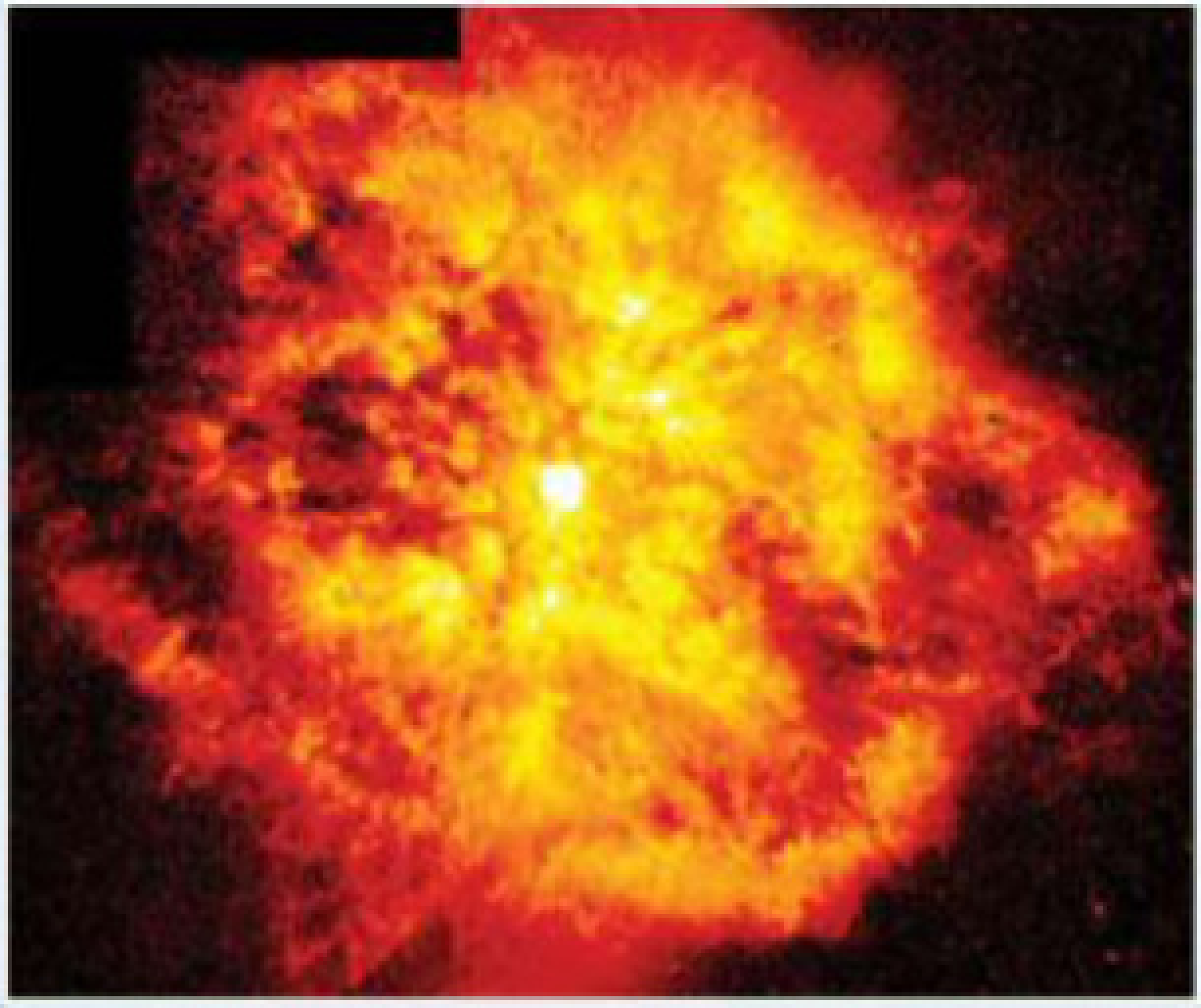
Antu
Designated UT1, the first of the VLT's primary telescopes to enter operation is equipped with a variety of objects for infrared and optical use.

Connected telescopes
An underground network of tunnels enables the telescopes to operate together as a single interferometer, making high-precision angular measurements.

The VLT sits at an altitude of 2,635 metres (8,645 feet) in one of the world's driest deserts, giving it a fine view of the southern skies, including the Magellanic Clouds

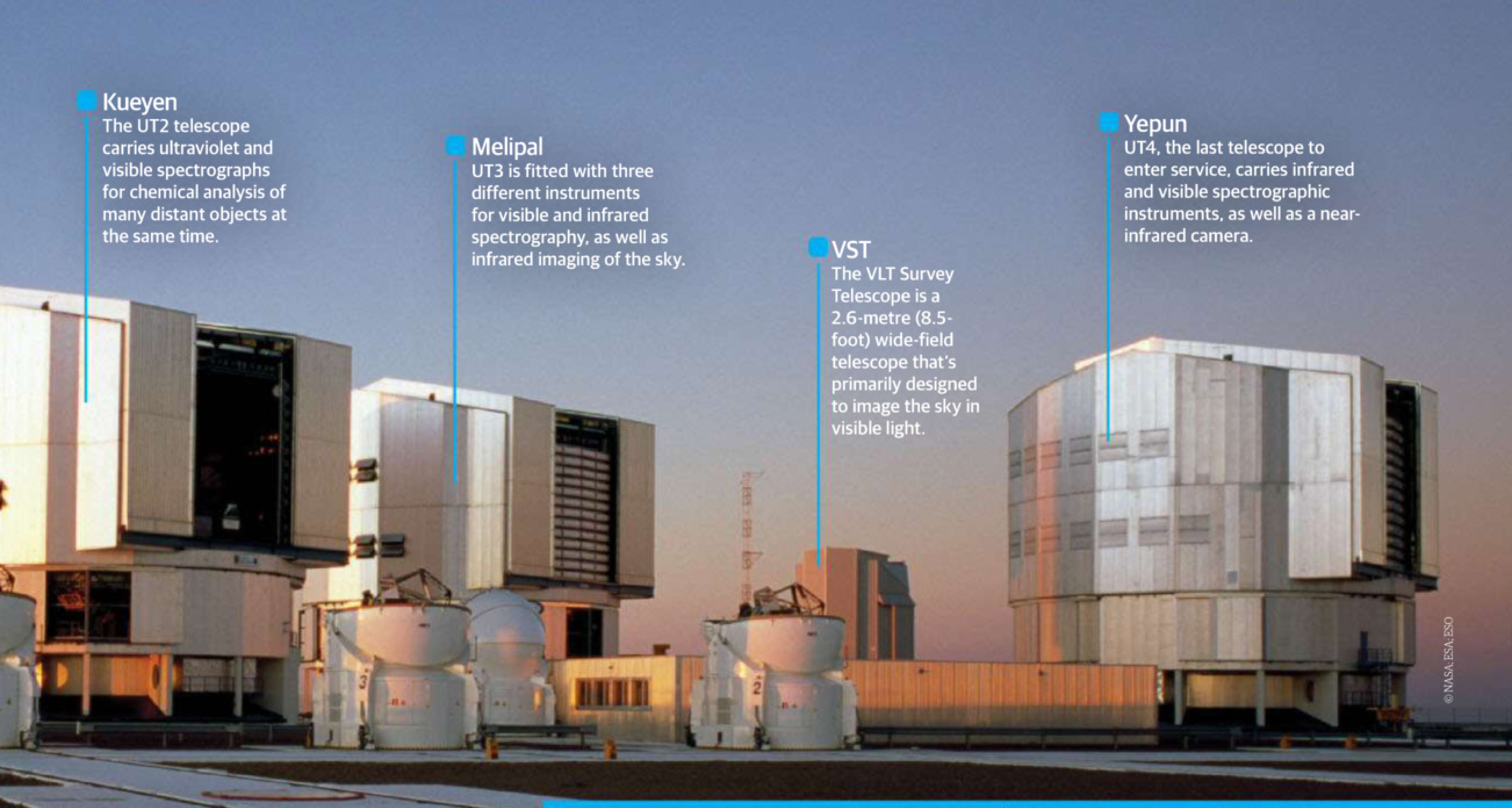


ESO's Multi-Conjugate Adaptive Optics Demonstrator (MAD) can correct for atmospheric turbulence



WR 124 is a Wolf-Rayet star some 15,000 light years from Earth. From this distance, the Hubble Space Telescope can see huge knots of gas blown into space

NGC 3603 is a much smaller open star cluster in our own galaxy, some 20,000 light years from Earth. Paul Crowther and his colleagues used a monster binary star in this cluster to refine their estimate of R136a1's mass



Kueyen
The UT2 telescope carries ultraviolet and visible spectrographs for chemical analysis of many distant objects at the same time.

Melipal
UT3 is fitted with three different instruments for visible and infrared spectrography, as well as infrared imaging of the sky.

VST
The VLT Survey Telescope is a 2.6-metre (8.5-foot) wide-field telescope that's primarily designed to image the sky in visible light.

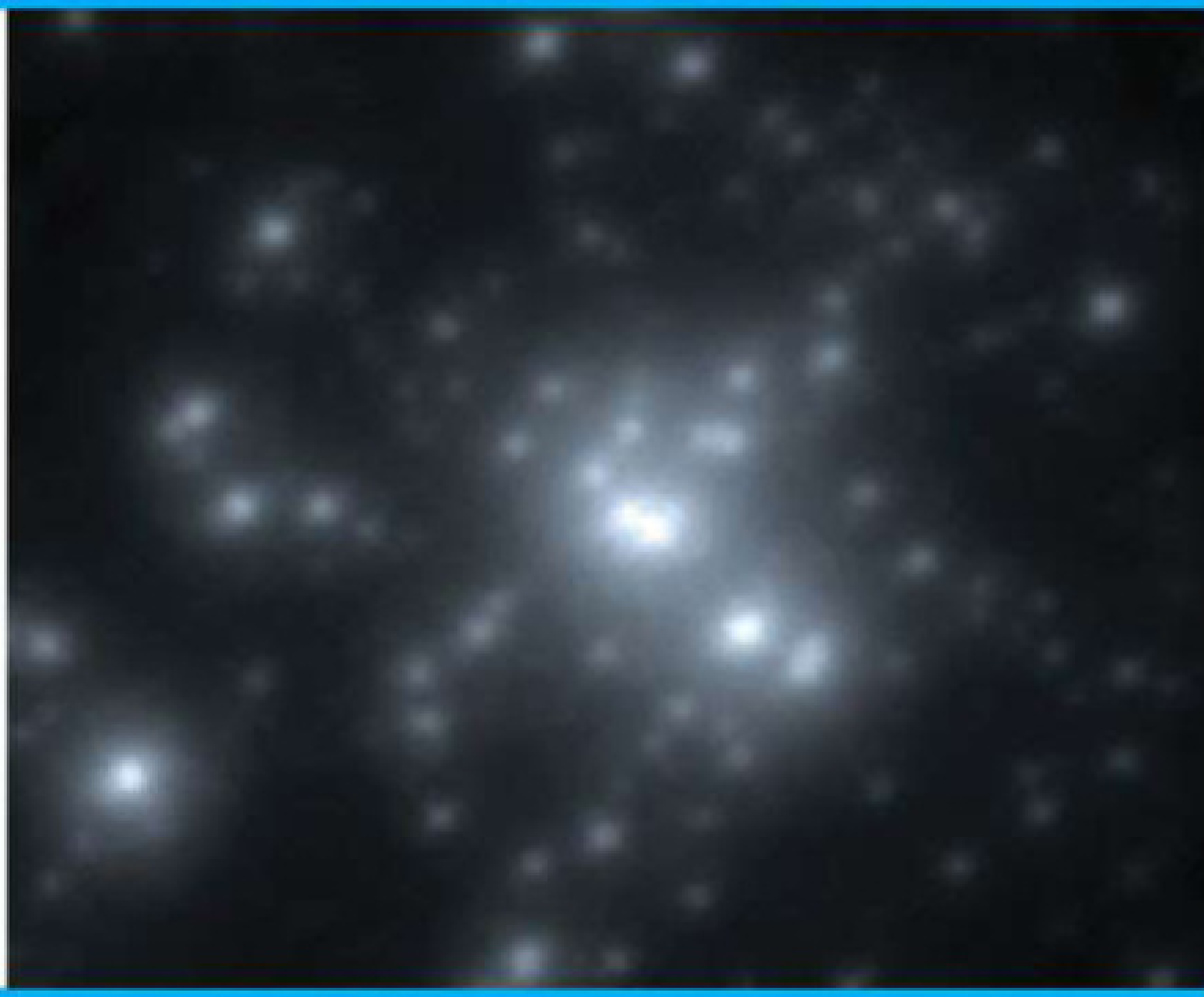
Yepun
UT4, the last telescope to enter service, carries infrared and visible spectrographic instruments, as well as a near-infrared camera.

© NASA; ESA; ESO

Weighing a giant

Confirmation of R136a1's enormous mass came from images and data collected using the MAD adaptive optics instrument on ESO's Very Large Telescope. This system monitors the appearance of a guide star very close to the target object in the sky, analysing the atmospheric changes that distort its image from moment to moment.

This information is then used to drive tiny motors that deform two small mirrors along the telescope's overall light path, correcting the original distortion to produce sharper images. Nevertheless, R136a1 and its neighbour a2 are only just distinguishable from each other in this near-infrared image.



Behemoth galaxy

At the heart of the giant Perseus cluster lies a monster of a galaxy

It seems appropriate that one of the most massive known objects in the universe, the Perseus galactic cluster, should also be home to a particularly huge galaxy at its centre. The giant elliptical NGC 1275 is 230 million light years away in the constellation of Perseus and actually consists of two galaxies - one a huge elliptical and the other a small spiral - in what's known as a high-velocity system.

These galaxies seem set to collide and are moving towards each other at 3,000 kilometres (1,864 miles) per second. This Hubble Space Telescope image shows filaments of cool, mainly hydrogen gas surrounded by gas measuring up to 55 million degrees Celsius (100 million degrees Fahrenheit) in the cluster, which emits strong X-rays.

The Perseus cluster has recently come under the spotlight of astronomers because it's the source of a particular X-ray signal that couldn't have come from ordinary matter. It's thought that an exotic particle called a sterile neutrino, which is related to dark matter, could be responsible. Study of the Perseus cluster, and other massive objects in the universe like it, is giving scientists a better idea of the nature of dark matter.

Filaments feed out of the giant elliptical galaxy NGC 1275 in searing-hot, X-ray-emitting gas in the Perseus cluster

© NASA/ESA

Lunar caving

We're ready to explore a cave recently found on the Moon – but how do we do that and what will we find?

It seems appropriate that, having left our caves over a million years ago in the pursuit of improving the quality of life for our species, we're now looking to return there for more or less the same reasons. This isn't on Earth of course, but on the Moon.

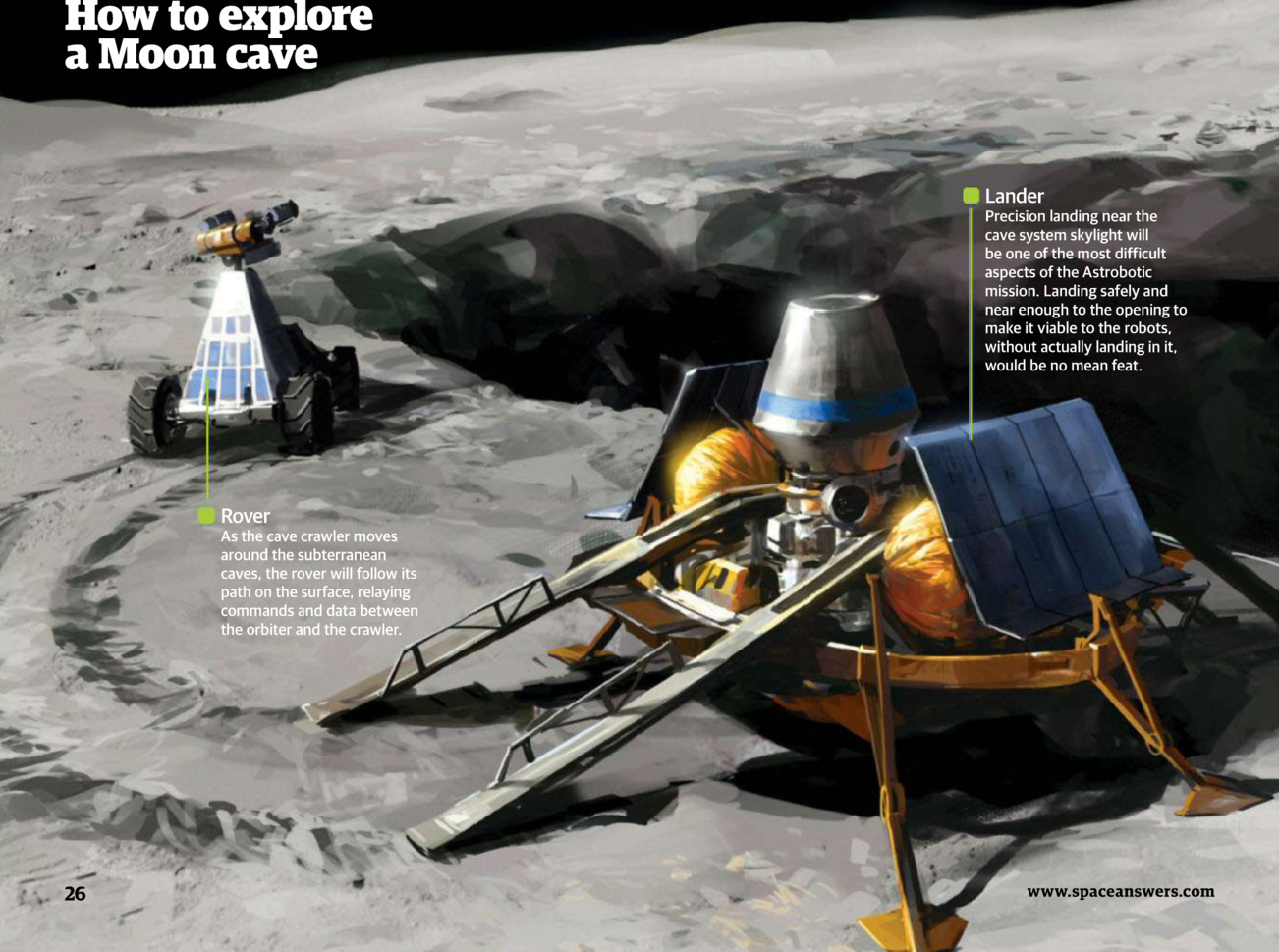
In 2009 a team of Japanese researchers led by Junichi Haruyama discovered a hole in the Marius Hills region on the near side of the Moon. This area is known for its ancient volcanism and is lined with long channels known as sinuous rilles. It's thought these were formed by lava that once flowed on the surface or through lava tubes.

The tubes and rilles are nothing to get excited about – evidence of this kind of geological activity can be found on other planets in the Solar System, including Mars. This hole is something special though – it isn't another crater formed by the impact of a meteorite or comet. After imaging the hole several times the team was able to calculate that it was 65 metres (213 feet) wide and 88 metres (289 feet) deep. In other words, it was deeper than it was wide, dimensions that are impossible for an impact crater. Also, it couldn't been the empty caldera of a long-extinct volcano, because there's no evidence of either ash or lava around the hole. This had to be the entrance to a cave, most likely a tunnel collapse on a lava tube with an estimated 370 metres (1,214 feet) of tunnel extending either side of the opening.

So, there's a cave on the Moon, what's the big deal? Let's set aside the insatiable desire we have for exploration that drives us to poke our noses into strange places (even though that's what got us into space in the first place) and look at the scientific merits of sending a mission to this phenomenon.

This cave could be a bit of a geological wonderland, giving us an unprecedented insight into the inner workings of the Moon, where hundreds of kilometres of these tunnels carrying rivers of lava ran beneath the lunar surface billions of years ago, emptying into the vast maria we can see from the Earth. It's possible that, since the lava flows have cooled and solidified, emptying out of the tubes, research into their formation could be conducted to ascertain their potential for collecting water on Mars. The Moon has no atmosphere, oceans or any life to disturb conditions in the lava tubes, so makes a better analogue to Mars than similar tubes found on Earth. Ultimately, investigating this lunar cave may

How to explore a Moon cave



Lander
Precision landing near the cave system skylight will be one of the most difficult aspects of the Astrobotic mission. Landing safely and near enough to the opening to make it viable to the robots, without actually landing in it, would be no mean feat.

Rover
As the cave crawler moves around the subterranean caves, the rover will follow its path on the surface, relaying commands and data between the orbiter and the crawler.

better prepare us for an investigation into whether life could have existed in comparable tubes on Mars.

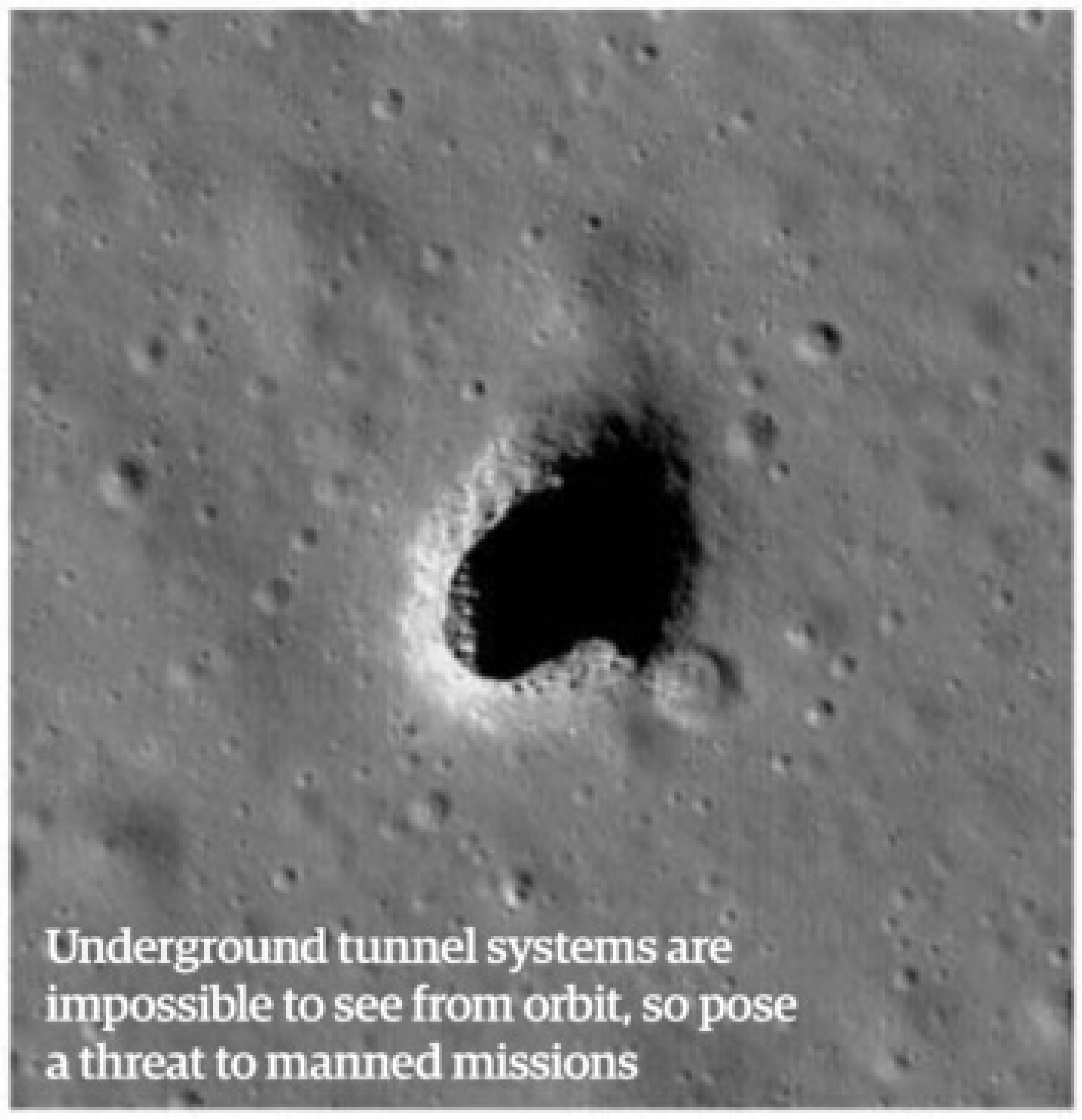
These tunnels could also be very cavernous in places and provide an ideal plot for a lunar base. The surface of the Moon is regularly bombarded with radiation and fluctuates wildly in temperature, from highs of over 100 degrees Celsius during the day and lows of less than -150 at night (212 to -238 degrees Fahrenheit). But the lunar surface itself is an excellent shield against deadly cosmic rays and solar radiation. Just two metres (6.6 feet) down, the temperature levels off to a fairly constant -30 to -40 degrees Celsius (-22 to -40 degrees Fahrenheit). You might think that we could dig this hole ourselves, of course, but setting up a construction site on the Moon with a view to excavating an enormous volume of lunar rock is a challenge for future generations of space engineers. So why bother, when there might be an ample, ready-made space right under our very noses?

Orbiter
The rover could communicate directly with Earth or possibly interact with an orbiter around the Moon, enabling mission control to direct the crawler through hazards and build an image of the cave's interior.

Cave crawler
The main robot in this mission will drop down through the skylight into the hole, rappelling off a line that's anchored to the much heavier lander.

Communication
Tens of metres of lunar rock will block higher-frequency communication between the crawler and mission control, so the cave radio transmits at a very low rate. This is relayed to the rover.

Robot spelunker



Underground tunnel systems are impossible to see from orbit, so pose a threat to manned missions

Before we pack up the camping gear and send an expedition to create an outpost on the Moon, we'll need to scout out Haruyama's cave – with robots of course. These tunnel systems can't be seen from orbit, so pose an unknown and unacceptable risk to any expensive expedition using astronauts. Technologically speaking, we're practically ready to send a robotic probe into the cave, however.

Pittsburgh-based private space exploration company and Google Lunar XPRIZE competitor Astrobotic already has a mission in development, scheduled to drop rovers on the Moon that will then explore Haruyama's cave and any others like it. These will relay data about the cave to the surface and from there back to Earth. From this data, we should be able to construct a three-dimensional model of the interior as well as determine whether a manned mission is feasible.

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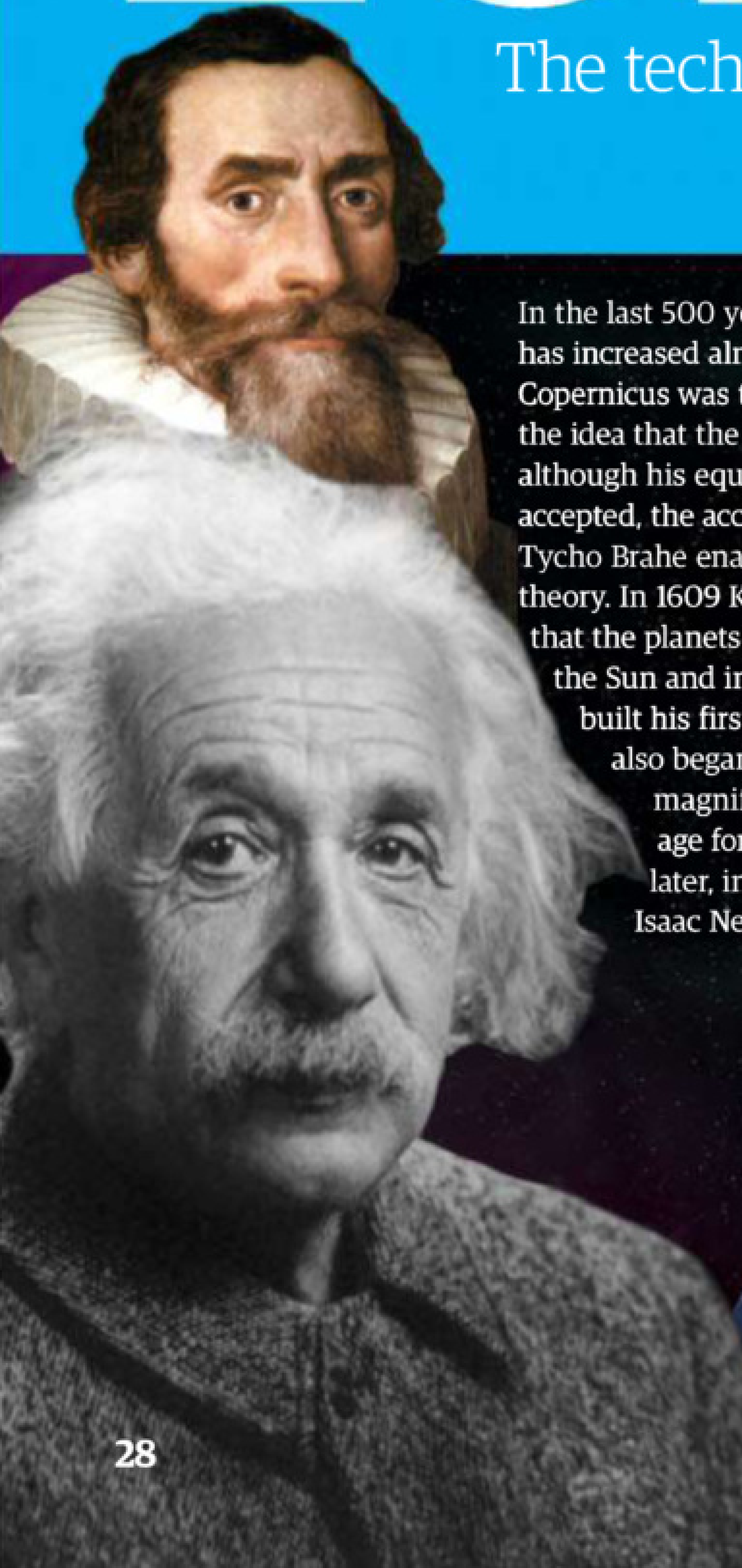
20 GROUNDBREAKING DISCOVERIES

The technology, theories and observations that changed the way we think about the universe

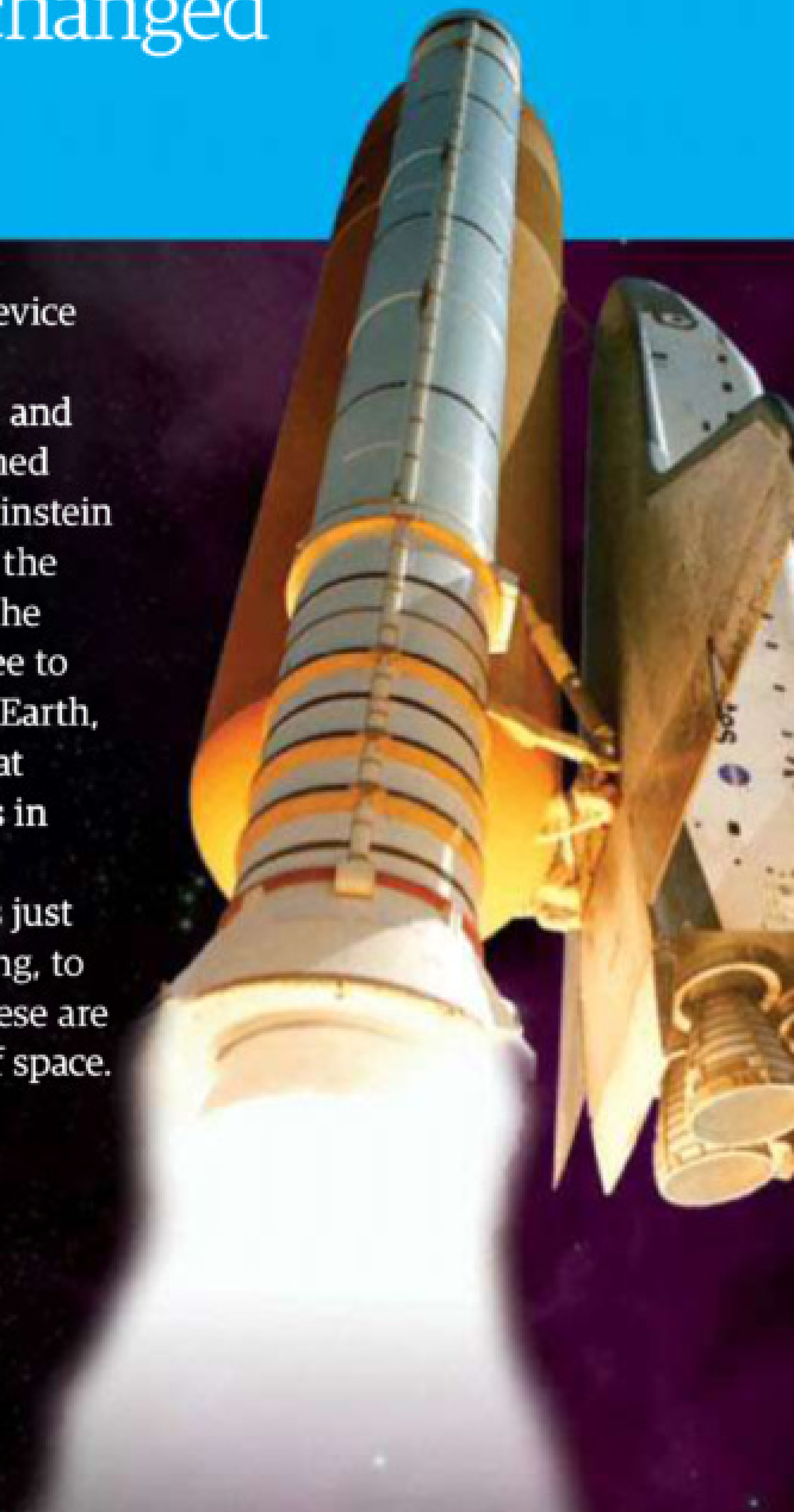
Written by Laura Mears



In the last 500 years our knowledge of the universe has increased almost exponentially. Nicolaus Copernicus was the first to formally introduce the idea that the Earth might orbit the Sun, and although his equations were not immediately accepted, the accurate record-keeping of astronomer Tycho Brahe enabled Johannes Kepler to finish the theory. In 1609 Kepler proved, for the first time, that the planets moved in elliptical orbits around the Sun and in the same year Galileo Galilei built his first refractive telescope. Astronomers also began observing the cosmos through a magnifying lens, which ushered in a new age for astronomy. Less than 60 years later, in 1668, the design was updated by Isaac Newton to include a mirror instead of a lens. This improved the resolution of the device even further.

Newton later published his laws of motion and theory of universal gravitation, which remained unchallenged until the 20th century when Einstein published his theory of relativity. Soon after, the rocket engine was developed and following the launch of Sputnik 1 in 1957 humanity was free to explore space away from the confines of the Earth, its atmosphere and its gravitational pull. What followed was one of the most prolific periods in space discovery.

From images of light emitted by universes just a few hundred million years after the Big Bang, to Earth-like planets that might harbour life, these are some of the biggest findings in the history of space.



1 Evidence of black holes

COSMOLOGY

Date discovered: 2001 **Discovered by:** Joseph Dolan

Like neutron stars, the concept of black holes started out in theoretical physics. English philosopher John Michell first proposed the idea of dark stars in 1783, suggesting that objects with sufficient gravity might be able to trap light, but it wasn't until the theory of general relativity that the idea started to take shape.

General relativity describes the event horizon, beyond which the gravitational pull is so great that nothing, not even light, can escape. Beyond this point the light is warped so that all paths lead towards the centre.

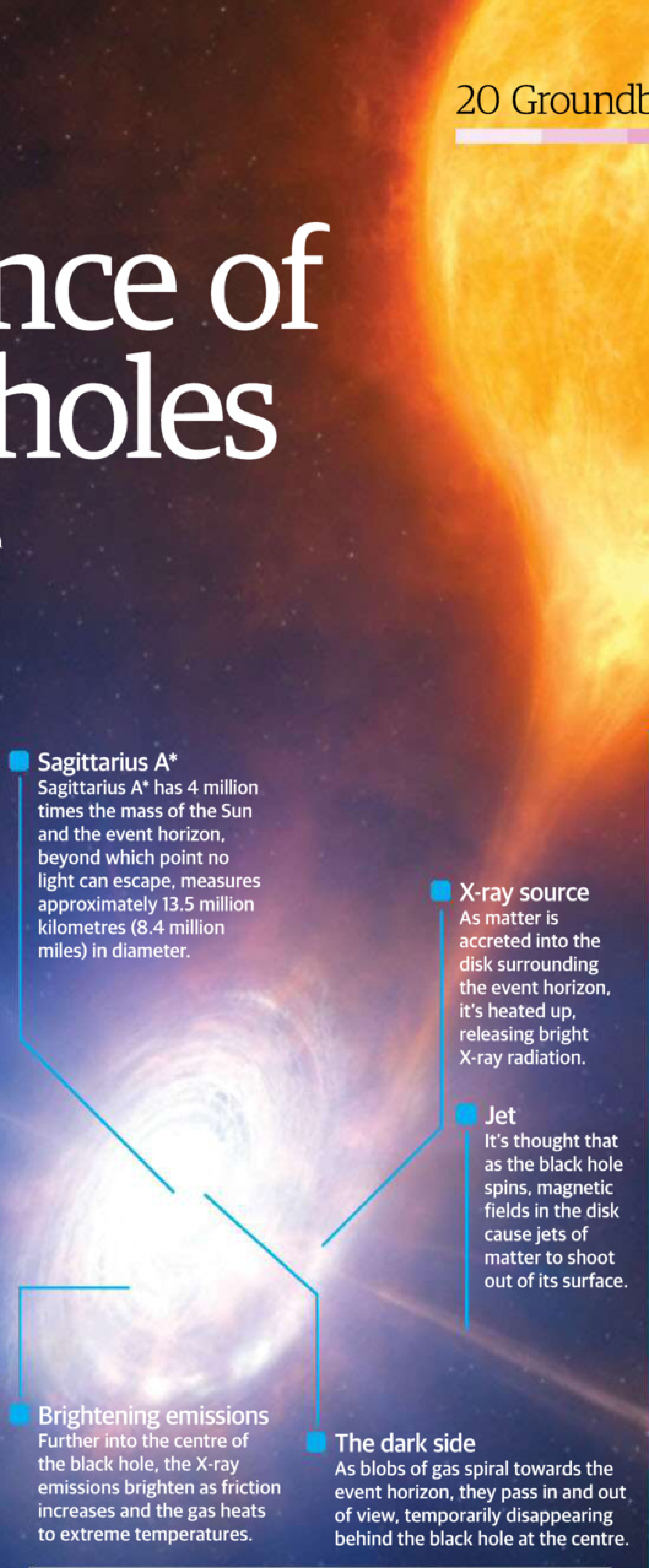
Some black holes are thought to be the size of a single atom and contain as much mass as a mountain, while others span millions of kilometres and contain billions of times more mass than the Sun. Despite the fact that, by their very nature, black holes are impossible to see, the affect they have on their surroundings is dramatic. But before the event horizon the pull of black holes can actually be seen.

The first black hole candidate to be identified was Cygnus X-1. In the 1970s the Uhuru satellite detected X-ray emissions from the Cygnus constellation. The nearby blue supergiant HD 226868 appeared to be part of a binary star system containing an X-ray source more massive than a neutron star.

In 2001 Joseph Dolan, an astrophysicist from NASA's Goddard Space Flight Center, observed Cygnus X-1 with the Hubble Space Telescope and for the first time saw material spiralling in towards a black hole. Cygnus X-1 and its companion form a binary star system and are both in orbit around one centre of mass. As the two move past each other, the gravitational pull of the black hole causes the star to bulge, stripping wisps of hot gas from the surface.

The gas encircles the black hole, forming an accretion disk that releases X-rays as friction heats the incoming gas. Instead of brightening as they reach the centre like they would with a neutron star, the X-rays flicker and dim.

The flickering is caused by blobs of hot gas as they break away from the accretion disk, falling towards the event horizon. As they spiral inwards, they emit a light signature known as a dying pulse train. When viewed from the Earth, the light flickers as the blobs pass behind the event horizon. By the time they return to a visible position in front of the black hole, they've spiralled further inwards and gravity distorts the light, stretching the wavelengths towards the red end of the spectrum. As the blob of gas grows closer to the event horizon, the pulses become weaker and more frequent, like water circling a drain, before vanishing forever.



Galactic centre
Lying at the centre of the Milky Way in the constellation of Sagittarius is a supermassive black hole called Sagittarius A*. It is about 26,000 light years away from Earth.

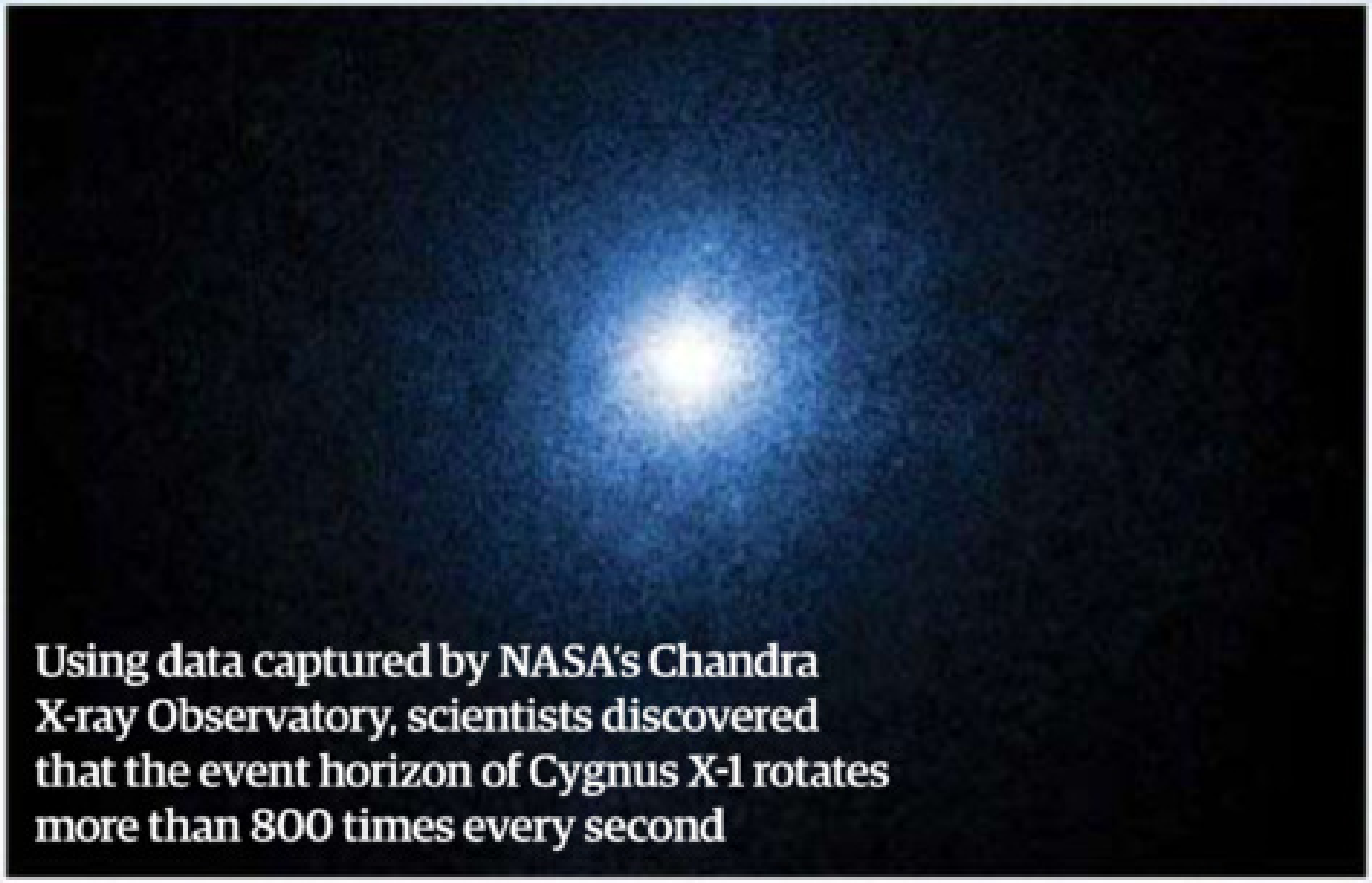
Sagittarius A*
Sagittarius A* has 4 million times the mass of the Sun and the event horizon, beyond which point no light can escape, measures approximately 13.5 million kilometres (8.4 million miles) in diameter.

X-ray source
As matter is accreted into the disk surrounding the event horizon, it's heated up, releasing bright X-ray radiation.

Jet
It's thought that as the black hole spins, magnetic fields in the disk cause jets of matter to shoot out of its surface.

Brightening emissions
Further into the centre of the black hole, the X-ray emissions brighten as friction increases and the gas heats to extreme temperatures.

The dark side
As blobs of gas spiral towards the event horizon, they pass in and out of view, temporarily disappearing behind the black hole at the centre.



Using data captured by NASA's Chandra X-ray Observatory, scientists discovered that the event horizon of Cygnus X-1 rotates more than 800 times every second

Interview

Dr Asa Bluck, research fellow at the University of Victoria, Canada

What is the best evidence that we have for black holes?

For 20 years astronomers have studied the detailed motions of 100 individual stars at the centre of our galaxy, around a mysteriously empty region known as Sagittarius A*. These orbits imply that there is a huge source of mass of over 4 million Suns cramped into a region not much bigger than our Solar System… [Here we] see no extra light, certainly nothing close to a million Suns' worth…

What makes the discovery of black holes so important?

[They] represent a pivotal turning point in our understanding of nature: they are regions of space where time itself comes to an end. They form as an inescapable consequence of Einstein's general theory of relativity, and their discovery and confirmation represent a huge success for physics… [The] most important aspect of black holes is that they go beyond even relativity – they predict a region of infinite density and pressure (the singularity) where the laws of physics will cease to exist. Today physicists interpret this as a sign that the theory of relativity is incomplete…

2 The accelerating expansion of the universe

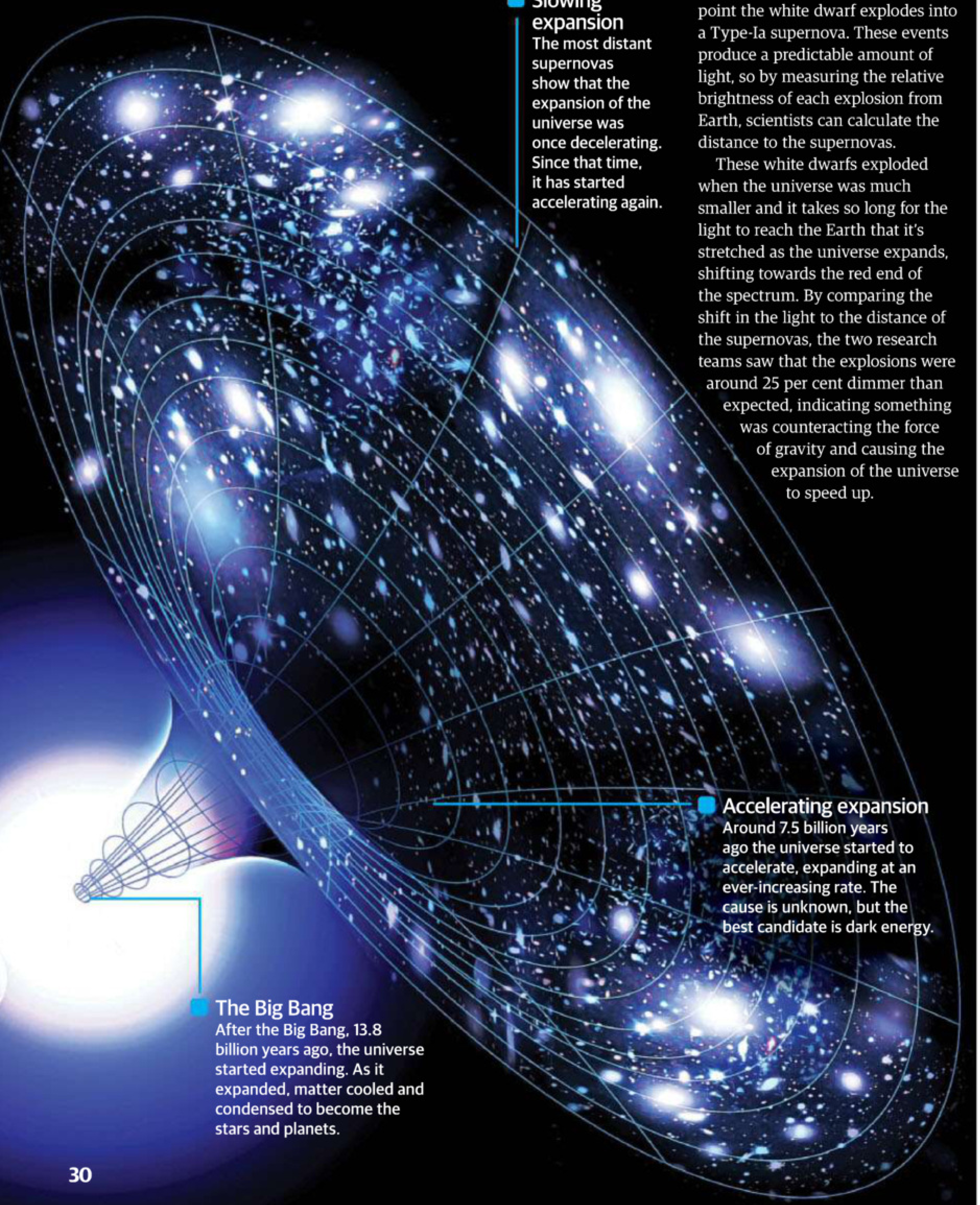
COSMOLOGY

Date discovered: 1998
Discovered by: Saul Perlmutter, Brian Schmidt and Adam Riess

Until 1998 the popular consensus was that the force of gravity would cause the expansion of the universe to slow, but two research teams, the Supernova Cosmology Project and the High-z Supernova Search Team, published data that suggested quite the opposite.

After neutron stars and black holes, white dwarfs are some of the densest objects in the known universe. In binary systems they feed off their companion star, accumulating matter until reaching a mass 1.4 times the Sun's. At this point the white dwarf explodes into a Type-Ia supernova. These events produce a predictable amount of light, so by measuring the relative brightness of each explosion from Earth, scientists can calculate the distance to the supernovas.

These white dwarfs exploded when the universe was much smaller and it takes so long for the light to reach the Earth that it's stretched as the universe expands, shifting towards the red end of the spectrum. By comparing the shift in the light to the distance of the supernovas, the two research teams saw that the explosions were around 25 per cent dimmer than expected, indicating something was counteracting the force of gravity and causing the expansion of the universe to speed up.



Slowing expansion
The most distant supernovas show that the expansion of the universe was once decelerating. Since that time, it has started accelerating again.

Accelerating expansion
Around 7.5 billion years ago the universe started to accelerate, expanding at an ever-increasing rate. The cause is unknown, but the best candidate is dark energy.

The Big Bang
After the Big Bang, 13.8 billion years ago, the universe started expanding. As it expanded, matter cooled and condensed to become the stars and planets.

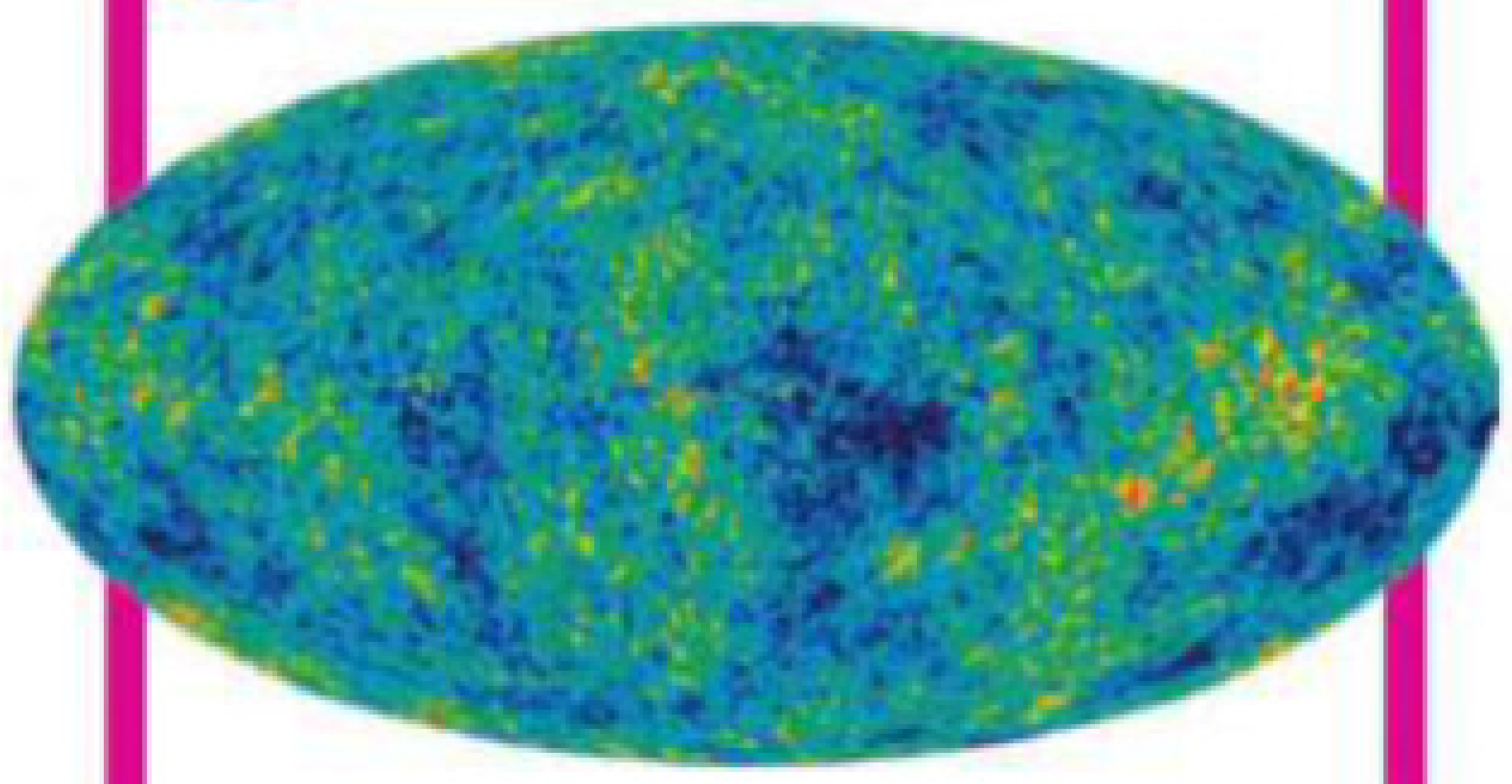
TECHNOLOGY

3 Reusable shuttles

Date discovered: 1981
Discovered by: NASA

NASA replaced expensive, single-use rockets with reusable shuttles, capable of launching like a rocket, but landing like a glider. The fleet of five shuttles made 135 trips before being grounded in 2011.

COSMOLOGY



4 Cosmic microwave background radiation

Date discovered: 1965
Discovered by: Bell Laboratories

Two engineers working for Bell Laboratories, Arno Penzias and Robert Wilson, provided some of the first real evidence of the Big Bang, detecting background noise on their microwave antenna. The snow was evenly distributed across the sky and represents the oldest light in the universe, created shortly after the Big Bang.

ASTROPHYSICS

5 Heliocentrism

Date discovered: c. 1515
Discovered by: Nicolaus Copernicus

Until the 16th century it was widely accepted that the Sun orbited the Earth, but Copernicus developed a model to show that this was impossible. This sparked a scientific revolution, inspiring other astronomers and permanently altering our view of the Solar System.

6 Halley's comet

PLANETARY SCIENCE

Date discovered: 1705 **Discovered by:** Edmond Halley

English astronomer Edmond Halley was investigating near-Earth comet flybys in the early 1700s when he found something unusual. He had gathered historical data spanning over 200 years and noticed that on three separate occasions, in 1531, 1607, and 1682, a comet with similar orbital properties travelled past Earth. Building on the earlier work of Copernicus and Kepler, plus the ideas of his friend Isaac Newton, he believed that these separate instances were the same comet, and that it too was in orbit around the Sun. He calculated that in 1758, the same comet would once again make a flyby.

Unfortunately, Halley died in 1742 but true to his predictions, the comet returned on Christmas night, 1758 and it continues to make its elliptical journey to and from the outer Solar System an average of once every 75 years. It appeared in the chronicles of Chinese astronomers, dated 239BCE, and was even stitched into the Bayeux Tapestry. When it reappeared in 1986, a fleet of spacecraft was sent to observe it as closely as possible. Halley's comet is due to return in 2061.

Halley's comet makes a flyby of the Earth once every 75 years

7 The Keck telescope revolution

TECHNOLOGY **Date discovered:** 1993 **Discovered by:** Jerry Nelson

The invention of the telescope in the 1600s was perhaps one of the most important historical advances in astronomy. At the time there was a flurry of innovation, but after Isaac Newton developed his reflecting telescope in 1668, the core design remained largely unchanged.

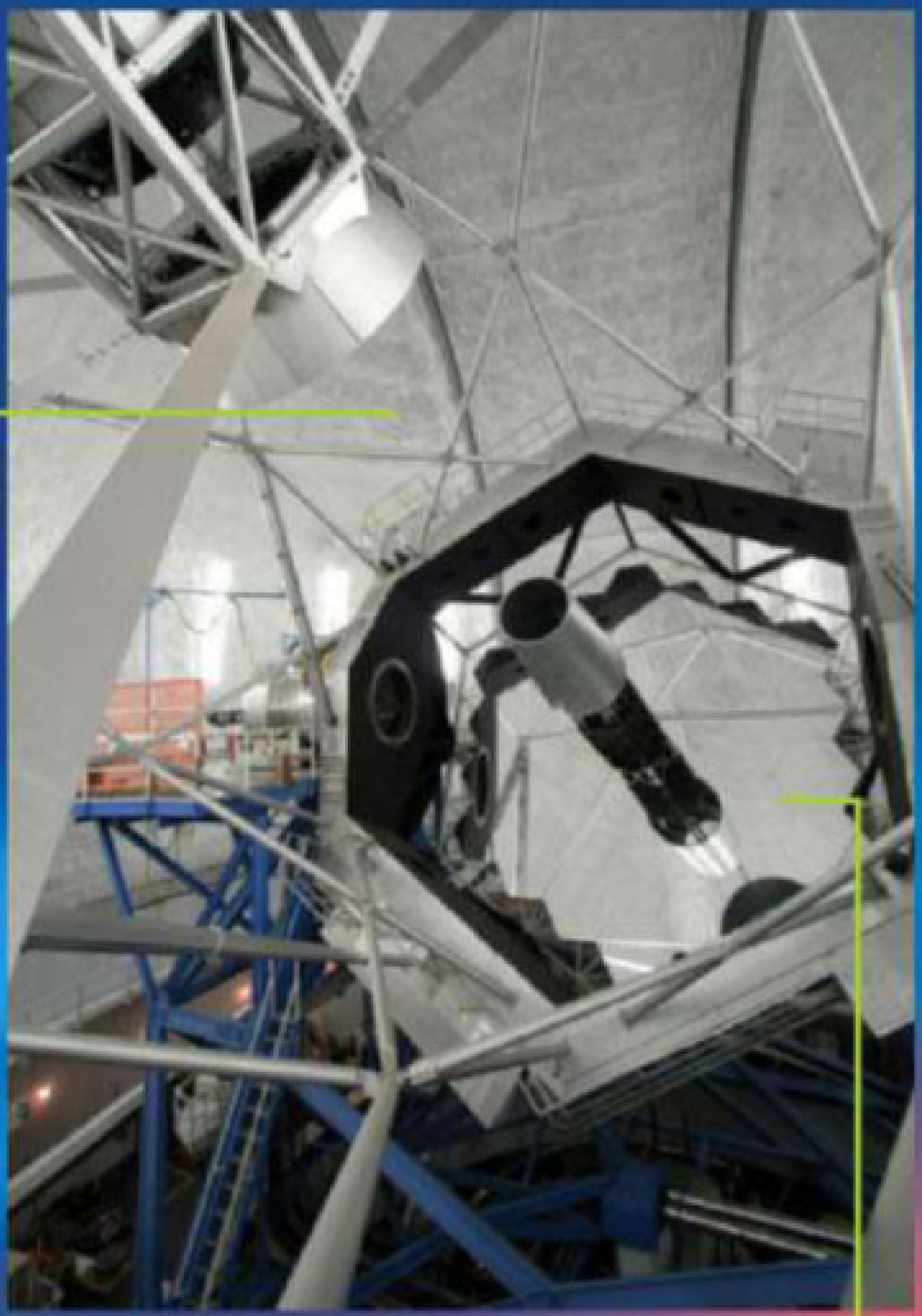
Reflecting telescopes use a curved mirror to capture light before reflecting it back to a focus point - this avoids any distortion created by glass lenses. The larger the mirror, the more light can be captured and the deeper into space the telescope can see.

Until 1993 the largest reflecting telescope in the world was the BTA-6, at the Special Astrophysical Observatory in Russia. Its six-metre (19.7-foot) reflector represented the upper limit for a solid mirror - any larger and not only would the reflector be too heavy to support, but the cost of production would be in the millions, even billions, of dollars.

Built in 1993, the Keck telescope was the first major advance in telescope technology for centuries. Astrophysicist Jerry Nelson pioneered the construction of a ten-metre (32.8-foot) mirror, capable of capturing light from objects 10 billion light years away.

In order to avoid the problems associated with a solid mirror, the reflector of the Keck telescope was built using 36 separate hexagonal segments, each measuring 1.8 metres (six feet) across and weighing half a ton. The segments were carefully warped before being cut and ground to form a perfect parabolic surface.

Minor disturbances in the alignment of the mirrors are continually monitored by 168 sensors and the segments are adjusted using 108 motors. Before its completion, and with just a quarter of the mirror in place, the Keck telescope was already able to match the capability of the BTA-6.

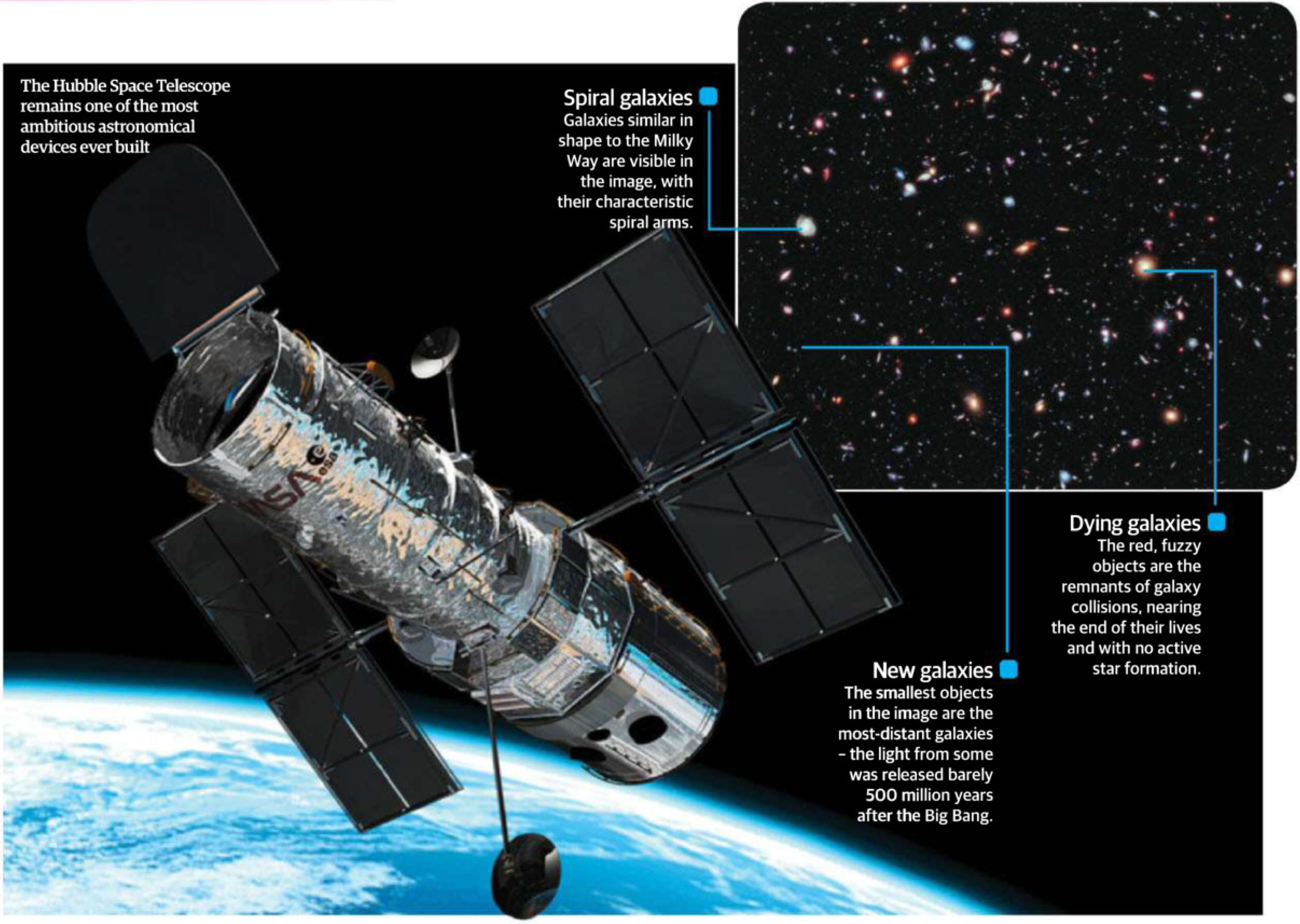


Structural support
Each mirror is individually supported, enabling the array to be adjusted. The support structure uses over 100 motors to keep the mirror in alignment.

Environmental control
To avoid distortion of the mirror, the dome of the observatory is insulated and coated with a thermal paint, and the air conditioning can replace the air in the room every five minutes.

Hexagonal mirrors
The Keck telescope design uses 36 separate hexagonal mirror plates, each measuring 1.8 metres (six feet) across. The plates are arranged into a smooth, parabolic mirror.

Keck represented a new pinnacle in the history of telescope design



The Hubble Space Telescope remains one of the most ambitious astronomical devices ever built

Spiral galaxies Galaxies similar in shape to the Milky Way are visible in the image, with their characteristic spiral arms.

Dying galaxies The red, fuzzy objects are the remnants of galaxy collisions, nearing the end of their lives and with no active star formation.

New galaxies The smallest objects in the image are the most-distant galaxies – the light from some was released barely 500 million years after the Big Bang.

8 The Hubble Deep Field

COSMOLOGY **Date discovered:** 1995-2012 **Discovered by:** The Hubble Space Telescope, NASA

Hundreds of thousands of images have been captured by the Hubble Space Telescope since its launch in 1990, but perhaps none quite so dramatic as the *Hubble Deep Field*.

The glare from nearby stars and galaxies outshines the weak signals from distant galaxies, so in order to see past this, the telescope was pointed at a seemingly empty portion of space, a tiny area measuring just one 24-millionth of the sky, in the constellation of Ursa Major. In 1995, 342 separate images were captured over a period of ten days and then painstakingly stitched together to form a single view. The resulting image was unprecedented. Almost 3,000 distant galaxies were revealed, some of which were the youngest and most-distant ever detected by an astronomical device.

In 2002 the Advanced Camera for Surveys was fitted to the Hubble Space Telescope, enabling it to see even further into space. From that, two even more-detailed images were created: the *Ultra Deep Field* in 2003-2004 and the *eXtreme Deep Field* (*XDF*).

The light from the youngest galaxy in the *XDF* image was emitted just 450 million years after the Big Bang, providing an unprecedented view back to the very beginnings of the universe. Working forwards in time from this point and looking through the field at galaxies closer to Earth, astronomers are able to see the changes as galaxies age.

Hundreds of thousands of images have been captured by the Hubble Space Telescope since its launch in 1990, but there's perhaps none quite so dramatic as the *Hubble Deep Field* photograph.

STS-125 mission specialists Michael Good and Mike Massimino repairing and upgrading Hubble

9 Rocket science

TECHNOLOGY

Date discovered: 1926 **Discovered by:** Robert Goddard

Rockets were first invented in ancient China, where bamboo tubes were filled with gunpowder and used to create fire arrows, but it wasn't until the early 20th century that modern rocket technology really began.

Until that point, rocket engines had all used solid fuel and had limited range, but in 1903 Russian school teacher Konstantin Tsiolkovsky published a comprehensive paper detailing how liquid fuels could be used to launch rockets into space.

His ideas were purely theoretical, but American engineer Robert Goddard had a similar idea and began tests using liquid rocket fuel. He launched his first rocket, named Nell, in March 1926. Nell flew for just 2.5 seconds for a total distance of 12.5 metres (41 feet). After a further 15 years of experimentation and 34 rockets later, Goddard's rockets were achieving speeds of 885 kilometres (550 miles) per hour and altitudes of 2.6 kilometres (1.6 miles).

During World War II, German engineers built an advanced rocket, the V-2. It was originally used to bomb London, but after the war the technology fell into the hands of the Allies. This sparked a technological revolution and when Sputnik 1 launched in 1957, propelled by a rocket engine, the era of space exploration began.

Interview

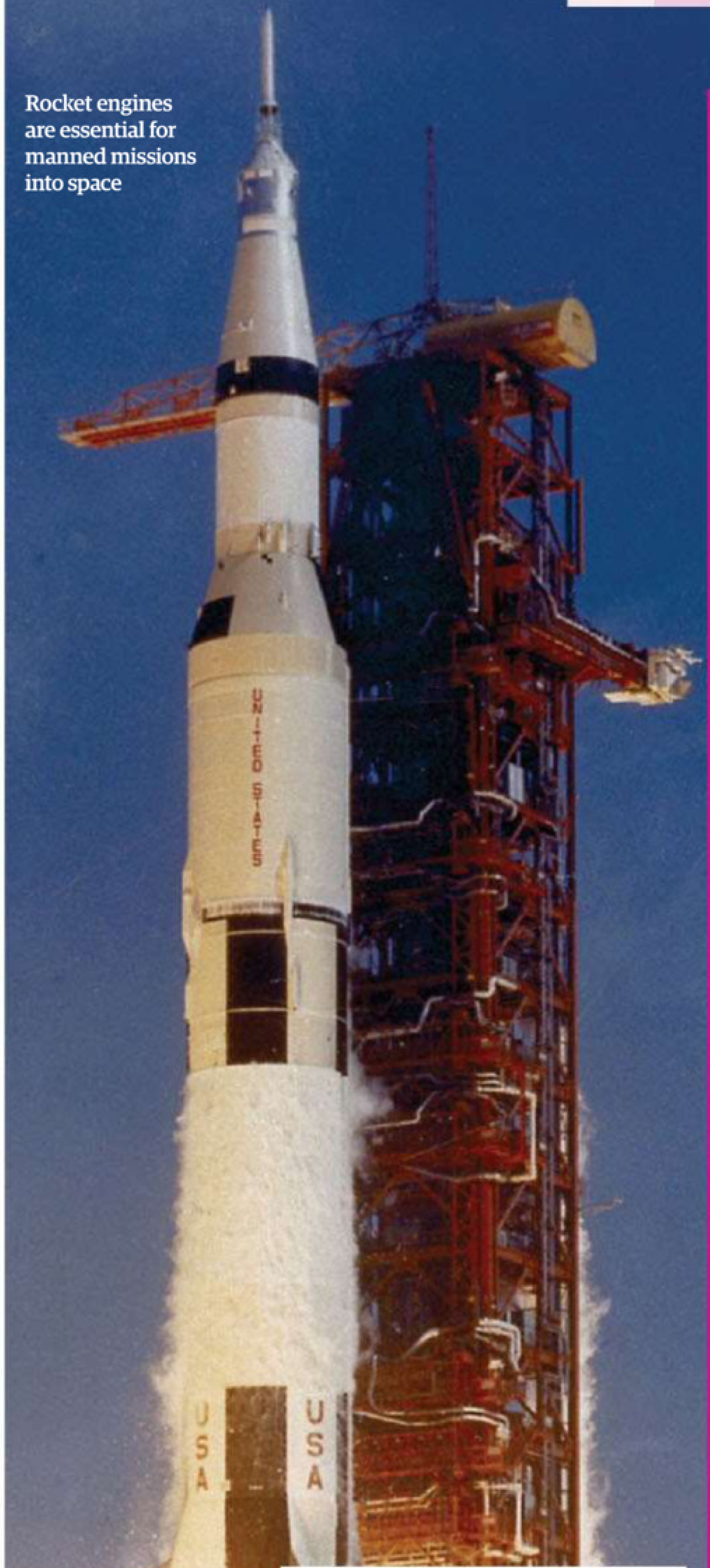
Thomas Benson, senior research engineer, NASA

What did the invention of the rocket engine do for space exploration?

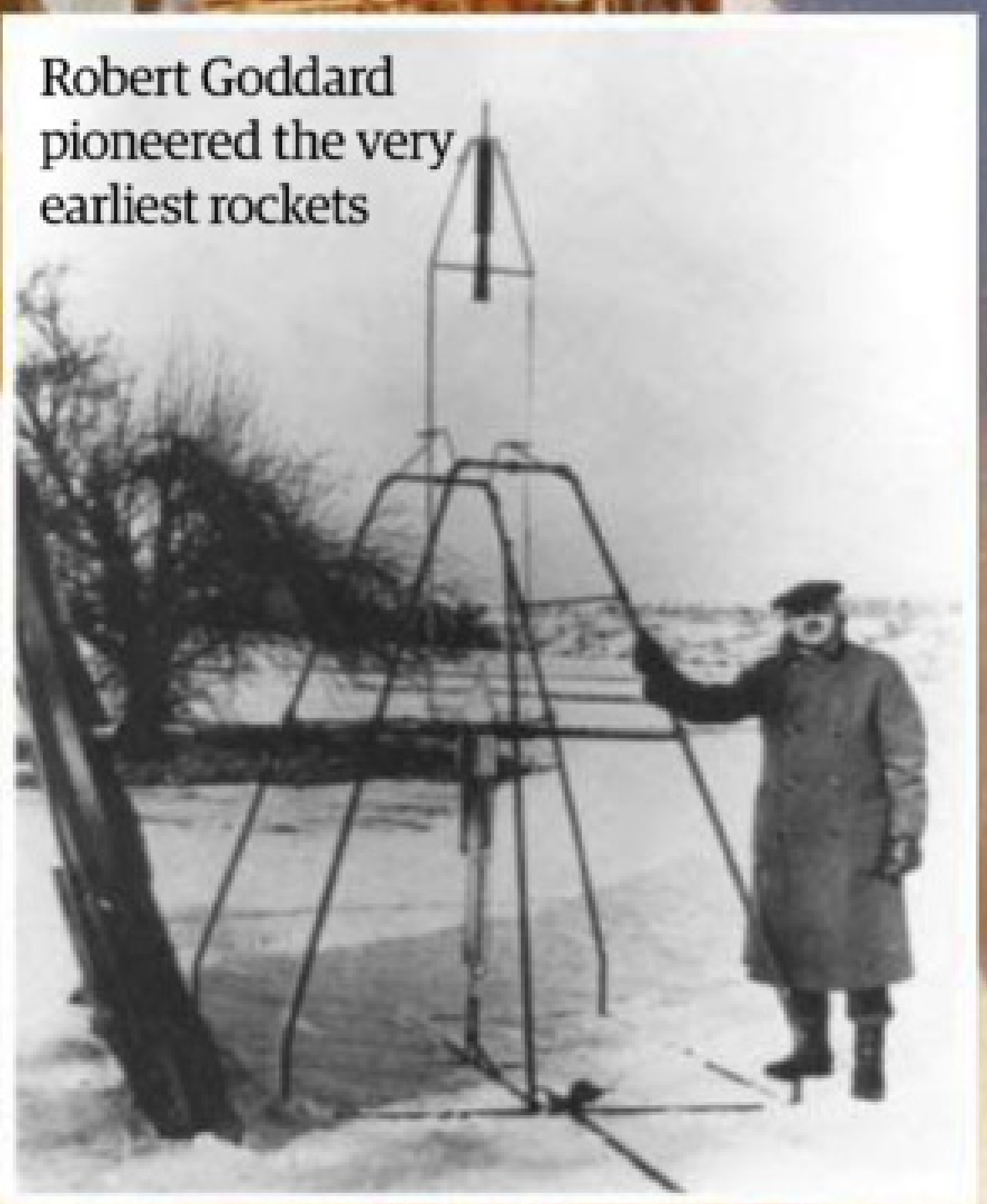
[It] enabled the manned exploration of space. Unlike a solid rocket engine, the liquid engine can be throttled, precisely stopped and restarted. The relatively safe liquid rocket engine has taken astronauts into low Earth orbit, onto the surface of the Moon and returned them safely to Earth.

How has the technology developed since the first rockets in the 1920s?

While the basic principles have remained the same, technology developments have enabled more-efficient liquid rocket operation. We can now obtain much more thrust per pound of propellant (fuel and oxidiser). Different propellant combinations are now also possible. Some explode on contact in the combustion chamber, greatly simplifying the design of the ignition system. Very cold liquid hydrogen and liquid oxygen propellants produce high thrust with a clean exhaust… The use of more-exotic materials in the engine itself has enabled higher temperatures in the combustion chamber and nozzle that produces increased thrust.



Rocket engines are essential for manned missions into space



Robert Goddard pioneered the very earliest rockets

ASTROPHYSICS

10 Sagittarius A*

Date discovered: 1974

Discovered by: Bruce Balick and Robert Brown

A mysterious radio source at the centre of the Milky Way was identified as a supermassive black hole Sagittarius A*, measuring 44 million kilometres (27 million miles) across.

TECHNOLOGY

11 Galileo telescope

Date discovered: 1609

Discovered by: Galileo Galilei

When the refracting telescope was invented in Holland in the 1600s, Galileo Galilei was fascinated. He built his own in 1609, gradually refining and improving upon the design. With his early lenses, he was the first to identify the four moons of Jupiter.

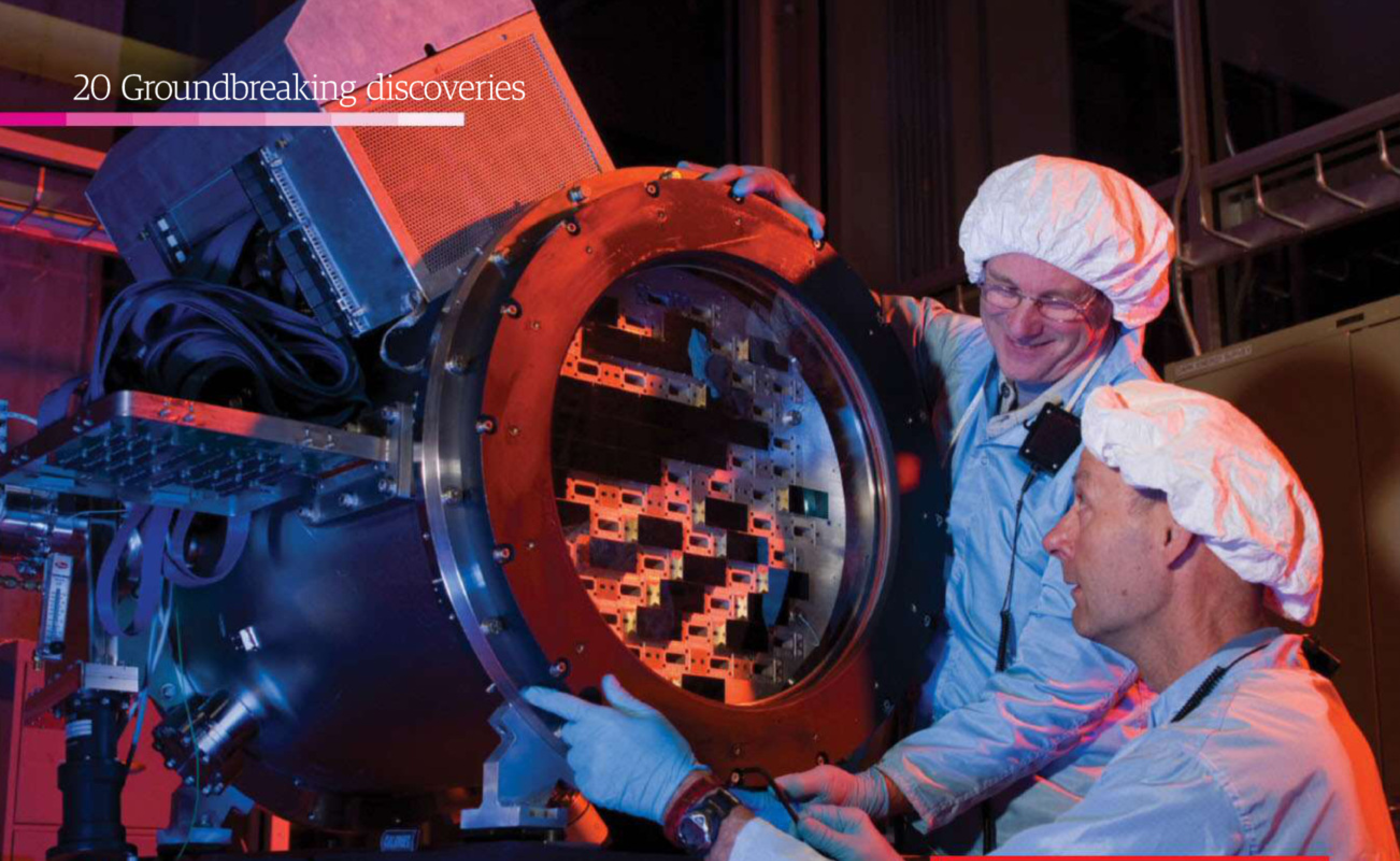
PLANETARY SCIENCE

12 Water on Mars

Date discovered: 2013

Discovered by: Curiosity Rover

NASA's Curiosity Rover returned compelling evidence that an ancient lake once existed on the surface of Mars, alongside several biologically important chemicals. The environment was described by lead scientist John Grotzinger as "benign and supportive of life", marking a major turning point in the exploration of the Red Planet.



13 Evidence of dark energy

ASTROPHYSICS **Date discovered:** 2008 **Discovered by:** István Szapudi

Einstein thought there may be a cosmological constant that keeps the universe in balance and that the energy associated with space could oppose the force of gravity. However, when it was eventually discovered that the universe was expanding outwards, he called this idea his "greatest blunder".

Nevertheless, in 1998 when it was discovered that the universe is not just expanding, it's actually accelerating, Einstein's idea started to make a whole lot more sense.

The expansion of the universe is being accelerated by dark energy, an unknown entity capable of opposing the force of gravity. Though this substance is still not fully identified, it's thought to make up around 73 per cent of the universe.

Some scientists believe that, like Einstein's cosmological constant, dark energy is a property of space itself and that as space expands, more dark energy is created, accelerating the expansion further. Other experts think that dark energy might make up a changing energy field known as quintessence and others still believe that our current understanding of gravity itself might be wrong.

In 2008 it was further shown that dark energy makes detectable changes to light as it passes through the bends in space-time caused by supervoids and superclusters.

Dark energy is a missing part of the galactic jigsaw

Interview

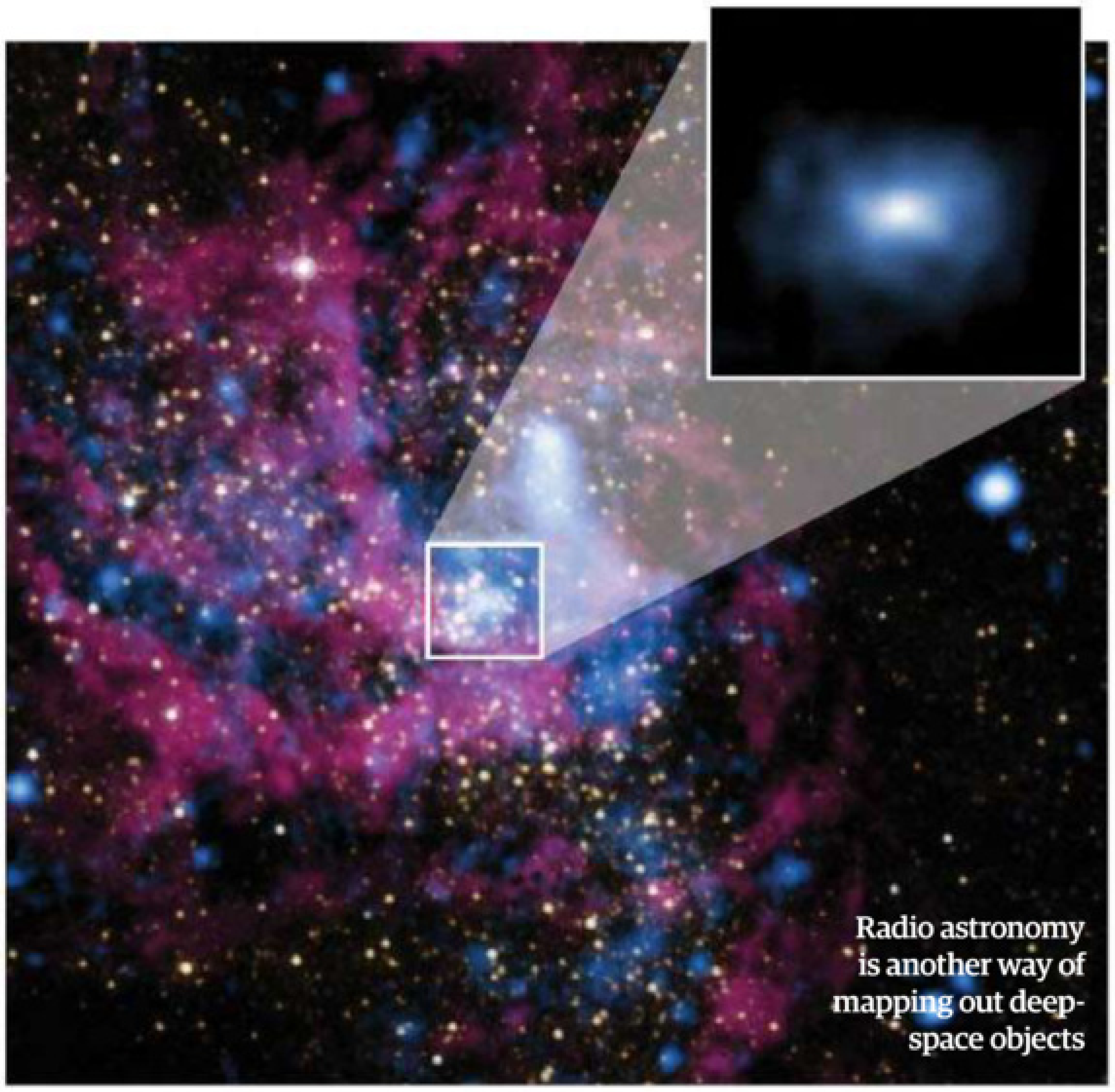
Prof Robert Caldwell, theoretical physicist, Dartmouth College, New Hampshire

What makes dark energy such an important idea?

Dark energy may very well comprise 75 per cent of the total energy of the universe. The large-scale structure of the universe, its origin and fate, may be entangled with the physics of dark energy. Its speculated existence raises more questions. Does dark energy have ties to cosmic inflation? Are are the laws of gravitation reliable on cosmic scales? Now that we know about dark energy, it seems pretty hard to ignore!

How do we know that dark energy exists?

We are not certain it does... But it seems to be one of the simplest inferences based on the observations and experiments. What we do know is that observations of supernovas, distant galaxies and extragalactic light all indicate that the expansion of the universe is accelerating. That leaves us with a puzzle, because general relativity should have predicted that the cosmic expansion was slowing down. But there is a loophole - if our inventory of cosmic energy is incomplete, and there is more out there (beyond atoms, light, neutrinos and dark matter), then the missing ingredient, dark energy, could be the answer.



Radio astronomy is another way of mapping out deep-space objects

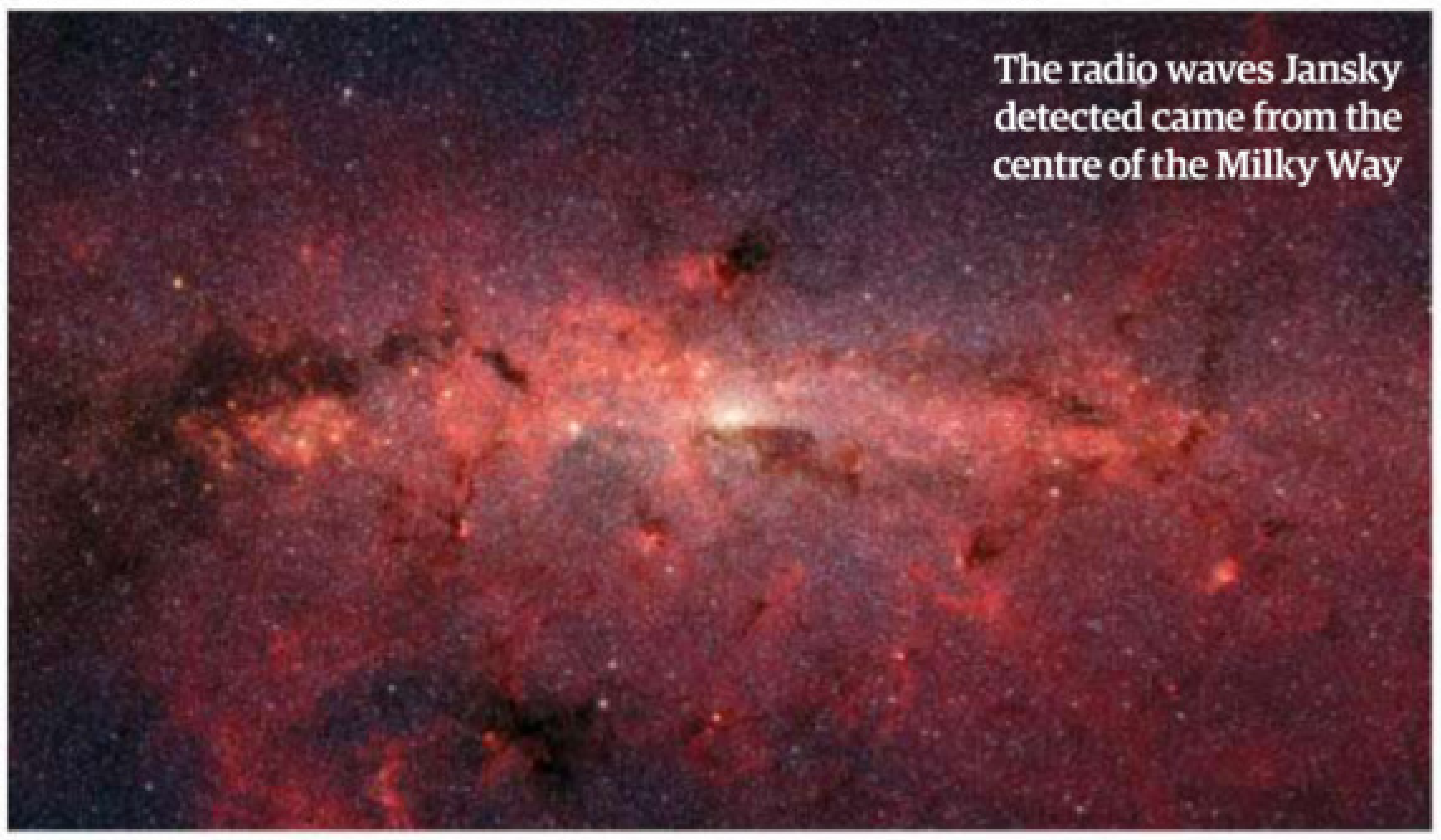
14 The Milky Way is a radio source

COSMOLOGY **Date discovered:** 1932 **Discovered by:** Karl Jansky

While working for Bell Telephone Laboratories in New Jersey in 1928, engineer Karl Jansky was tasked with investigating sources of static that might interfere with telephone communication across the Atlantic. Using a radio antenna and turntable known as Jansky's merry-go-round, Jansky scanned the sky for radio sources, pin-pointing their location. Most of the static that he detected could be explained by near or distant thunderstorms, but there was a steady hiss that rose and fell each day, the origin of which was unknown.

Jansky originally thought that the signal might be coming from the Sun, but it repeated once every 23 hours and 56 minutes - the time it takes the Earth to rotate relative to the rest of the cosmos. This indicated that the source was likely a distant star. The signal was localised to the Sagittarius constellation and is now known to be coming from the black hole at the centre of the galaxy, Sagittarius A*.

Jansky eventually published his findings and although Bell Laboratories would not support further research into the mysterious radio signal from the centre of the galaxy, his work inspired a generation of scientists and marked the beginning of radio astronomy.



The radio waves Jansky detected came from the centre of the Milky Way

15 Kepler's laws of planetary motion

ASTROPHYSICS

Date discovered: 1609

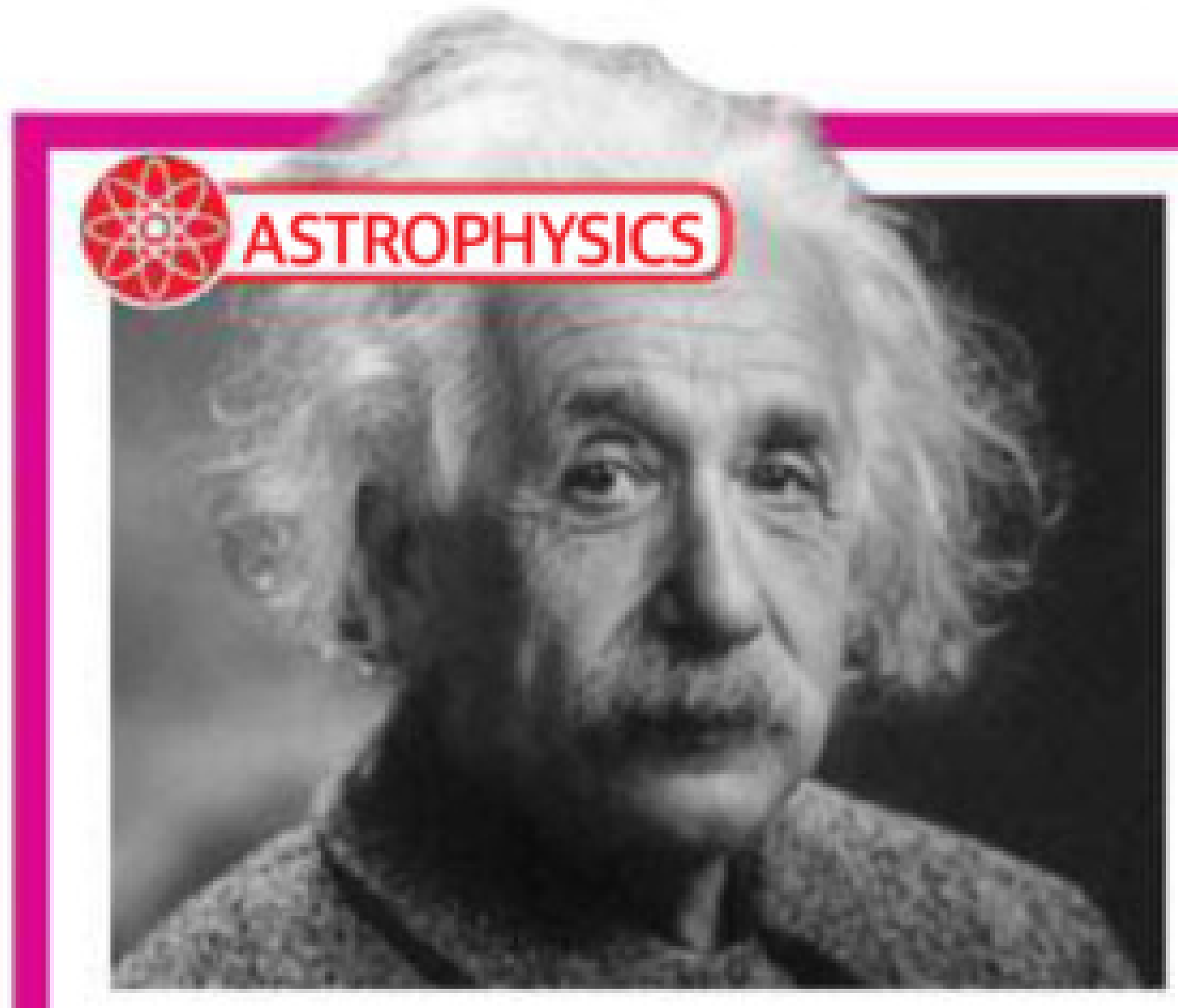
Discovered by: Johannes Kepler

As a graduate student, German mathematician Johannes Kepler studied the work of Copernicus and in 1600 became assistant to astronomer Tycho Brahe, who had been compiling accurate measurements of the positions of the stars and planets.

Brahe believed the Sun orbited the Earth and kept many of his observations secret from Kepler but, after his death in 1601, Kepler continued his work. He spent years trying to make Brahe's observations match the circular orbits predicted by the astronomers of the time but then focused on the movement of the planets in relation to the Sun.

Kepler showed that the planets move in elliptical orbits, and his three laws of planetary motion marked a turning point in astronomy and physics, providing part of the foundation for the work of Newton.

Kepler's three laws of planetary motion were a breakthrough for science



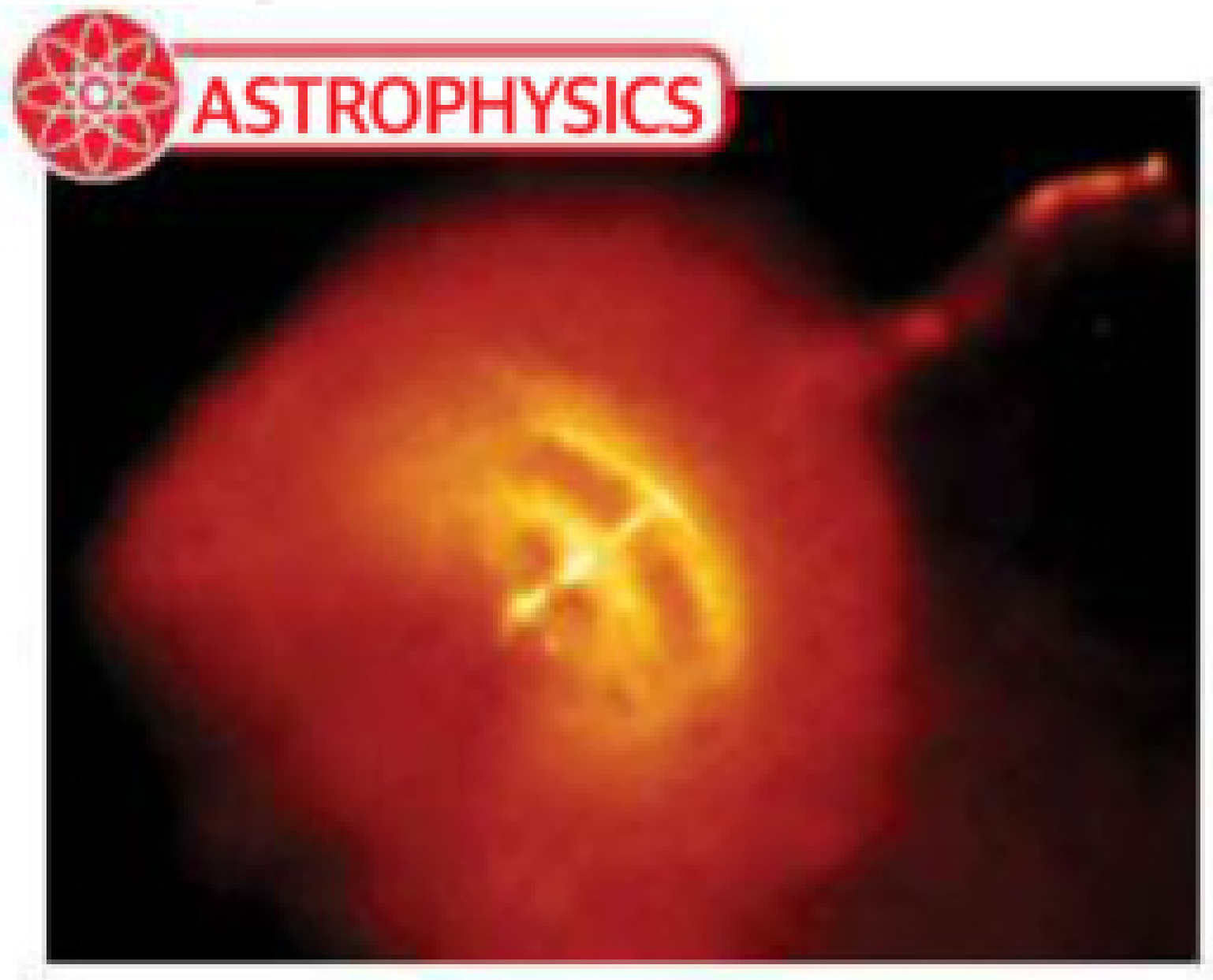
ASTROPHYSICS

16 General relativity

Date discovered: 1915

Discovered by: Albert Einstein

Einstein showed that space and time are inextricably linked and revolutionised our understanding of gravity. His theory of general relativity explained that matter and energy could distort the fabric of space-time, producing valleys and ripples like dents made by balls on a trampoline.



ASTROPHYSICS

17 Pulsars

Date discovered: 1967

Discovered by: Jocelyn Bell

In 1967 PhD student Jocelyn Bell was operating a new radio telescope in Cambridge, UK, when she picked up a series of even pulses 1.3 seconds apart. When she and her supervisor discovered three more, they realised the pulses were produced by rapidly spinning neutron stars - pulsars.

PLANETARY SCIENCE

18 Earth's twin

Date discovered: 2014

Discovered by: Kepler Space Telescope

Kepler-186f is the most Earth-like planet ever identified and represents a step forward in the search for life. It's only marginally larger than Earth and sits in the Habitable Zone, where it's possible liquid water could exist.

19 Discovery of Eris

PLANETARY SCIENCE

Date discovered: 2005 **Discovered by:** Mike Brown

In 2003 a potential tenth planet was spotted. Mike Brown and his team at the California Institute of Technology identified a bright object in the outer Solar System, nicknamed Xena. Over 10 billion kilometres (6.3 billion miles) from the Sun, Xena had an even more elliptical orbit than Pluto and took over twice as long to complete an orbit. They published their findings in 2005 and Xena was renamed Eris.

In 2006 the International Astronomical Union (IAU) stated that within the Solar System a planet must meet three basic criteria. First it must orbit the Sun; second it must have enough mass to form and maintain a spherical shape; third it must have cleared the neighbourhood around its orbit. Although Pluto and Eris meet the first two criteria, they fail to achieve the third; Pluto is part of the Kuiper belt and Eris belongs to the scattered disc, both of which contain other, similarly sized objects.

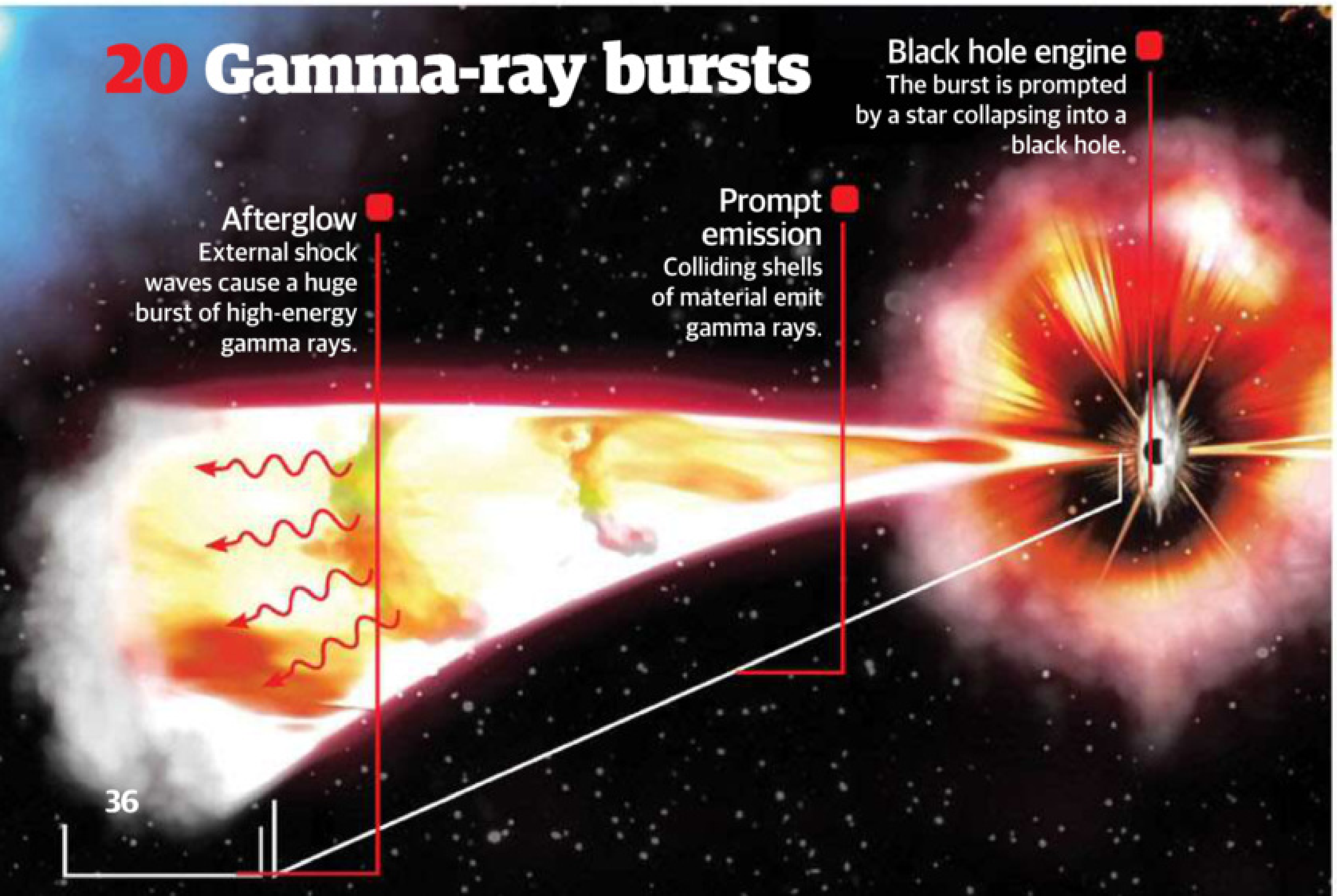
Interview

Michael Küppers, planetary scientist, ESA

"When the first Kuiper Belt objects were discovered in the 1990s, it became clear that Pluto wasn't dynamically unique in the sense that there are many objects on similar orbits. However, it was still the largest and it could be argued that it's still distinct because the others were too small to have an atmosphere (like Pluto does) or to maintain spherical shape. Therefore it was still justified on physical grounds to have Pluto stand out and call it a planet.

"This changed in the 2000s with the detection of large Kuiper Belt objects, in particular Eris, which is more massive and possibly also larger than Pluto. Just like Pluto, Eris has a moon and its surface composition is similar. It is expected to form an atmosphere when getting closer to the Sun (it's currently so far away that the main atmospheric constituents are frozen). So Pluto does not stand out anymore compared to other large Kuiper Belt objects and it cannot be called a planet anymore on physical grounds (unless one adds a whole lot of new planets). That was a decisive point in the demotion of the status of Pluto."

20 Gamma-ray bursts


Black hole engine
The burst is prompted by a star collapsing into a black hole.
Afterglow
External shock waves cause a huge burst of high-energy gamma rays.
Prompt emission
Colliding shells of material emit gamma rays.

ASTROPHYSICS

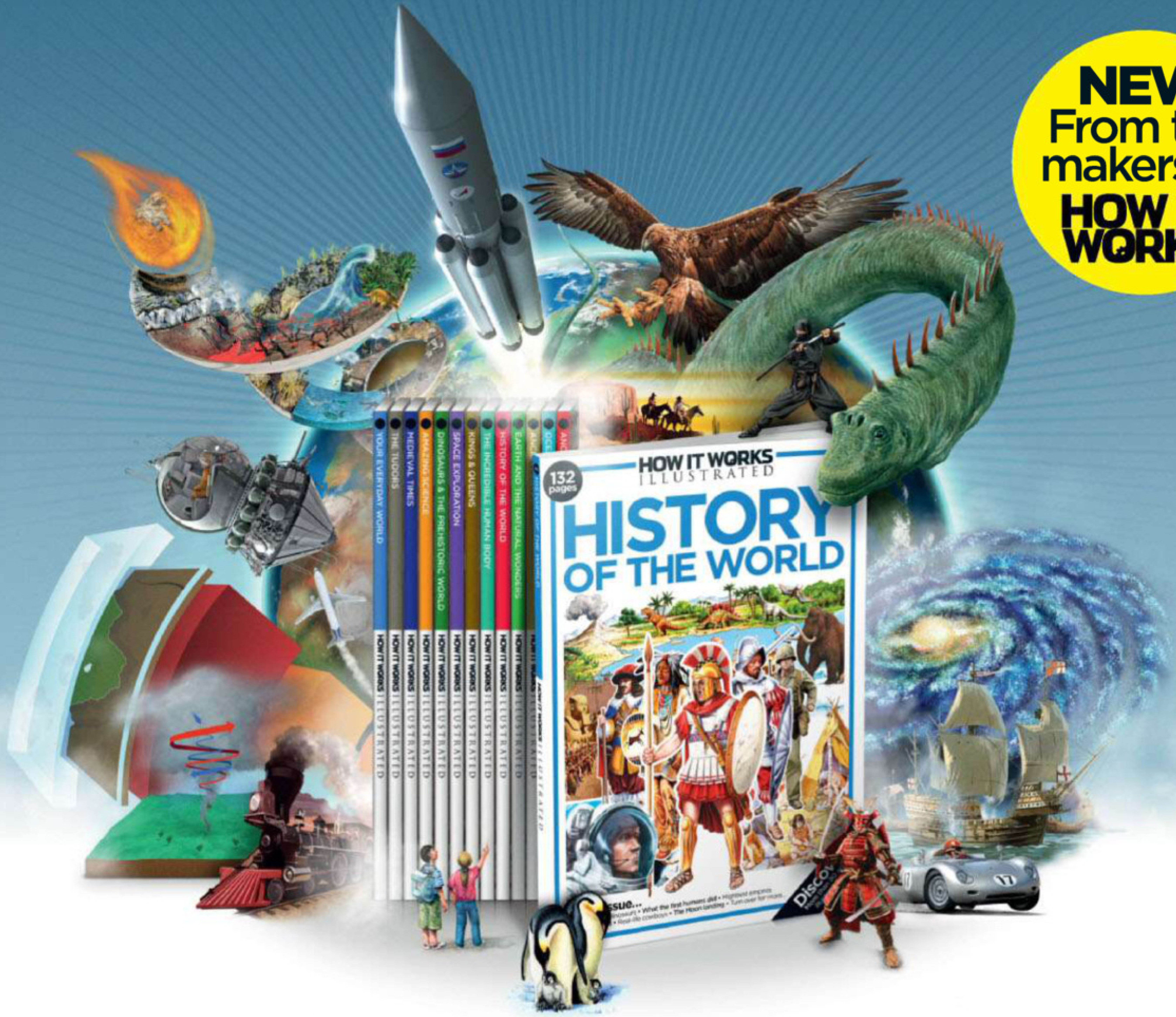
Date discovered: 1967 **Discovered by:** Ray Klebesadel

In the 1960s the USA signed the Partial Nuclear Test Ban Treaty with the Soviet Union and the United Kingdom. The aim of the treaty was to slow the threatening nuclear arms race and to limit release of fallout into the atmosphere.

The Vela nuclear test-detection satellites carried X-ray and gamma-ray receivers that were launched to monitor compliance with the ban, but unidentified flashes of radiation were spotted in the data.

The satellites were launched in pairs, positioned around 250,000 kilometres (155,000 miles) apart, on opposite sides of Earth. Suspecting illicit nuclear testing, scientists used the time delay between the signals to determine that the bursts were not coming from Earth, or from the Sun, but from space.

Gamma-ray bursts last just a few minutes and represent the brightest electromagnetic events in the known universe. They are thought to be the result of extremely energetic supernovas or hypernovas.



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How big were the dinosaurs? Find out in issue one

big

How big were the dinosaurs?

Dinosaurs were the **largest** animals ever to walk the Earth. Some of them were **taller than trees**, longer than **aeroplanes** and **heavier** than a herd of **elephants**.

Sauroposeidon

Argentinosaurus

Did you know?

Brachiosaurus

Diplodocus

Tyrannosaurus rex

Spinosaurus

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IMPACT ON JUPITER

Relive the explosive meeting between planet and comet that gripped the world's media 20 years ago this month

Written by Gemma Lavender

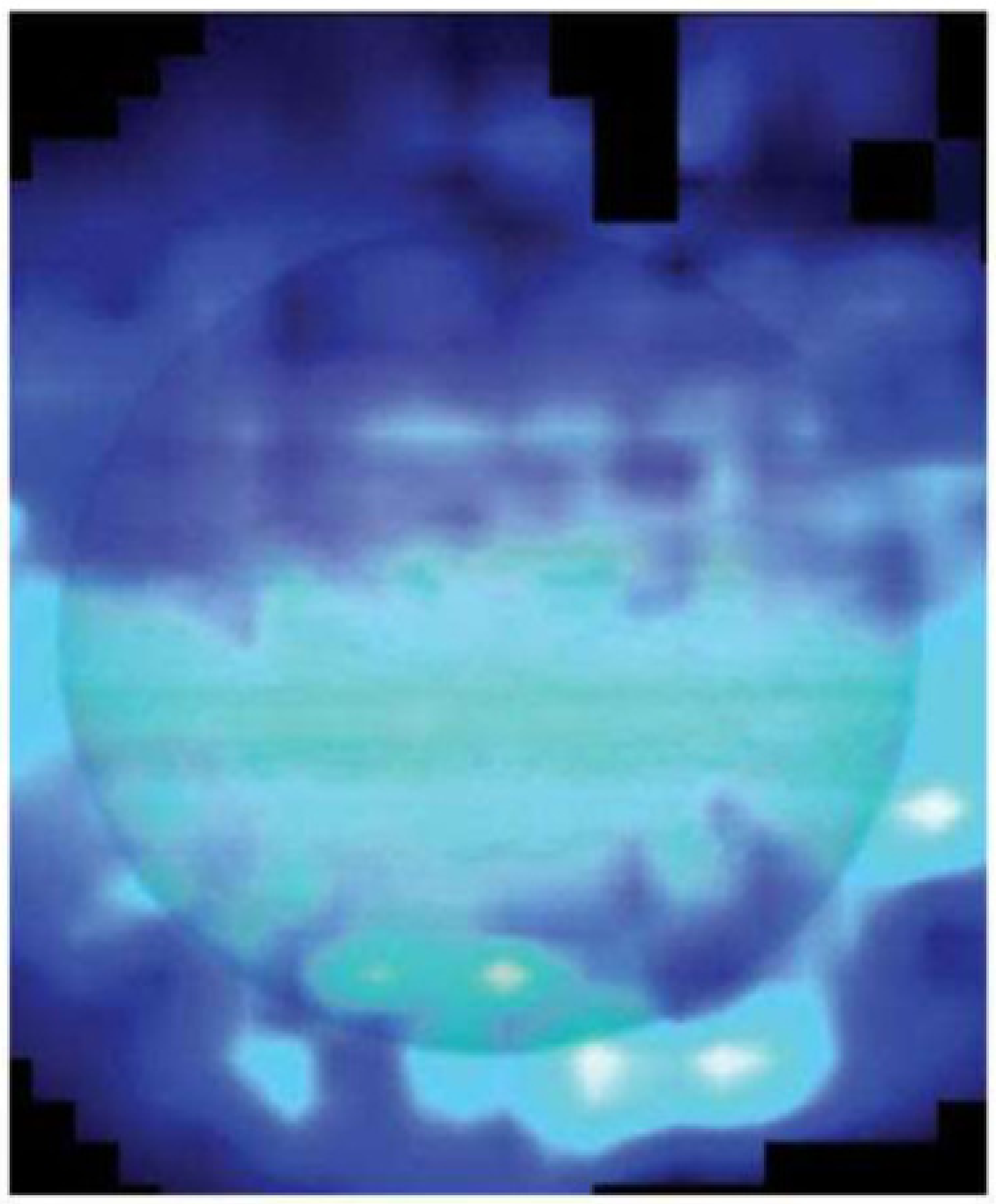
Comet Shoemaker-Levy 9 was the comet that dared to strike the king of the Solar System. It's true that Jupiter takes the brunt of the Solar System's wayward debris, colliding with its gaseous bulk, but this event was nothing that the astronomical community had ever witnessed in the past or could have anticipated.

It all began during a hunt for space rock on a potentially deadly collision course with our planet, in a program that intended to get to these dangerous near-Earth objects before they got to us. Astronomers trusted the 0.4-metre (1.3-foot) Schmidt telescope at the Palomar Observatory with this important task. Snapping away at the night sky, the Californian telescope tirelessly stood sentry night after night. Its photographic findings were later pored over by astronomers in a bid to detect the one object that could wipe us out, whether it was an asteroid or comet. On the evening of 24 March 1993, three astronomers - Eugene and Carolyn Shoemaker alongside David Levy - were poring over one particular image produced by Palomar, and what they found defied all expectations. Carolyn was originally scanning the images that the three had taken that night, when she found what she felt was an oblate, comet-like object.

This turned out to be Comet Shoemaker-Levy 9, their ninth periodic comet, whose orbital period took less than 200 years. However, this wasn't what was so unusual about it. Its squashed appearance was telling the astronomers something important: that Shoemaker-Levy 9 wasn't orbiting the Sun. Instead it had been captured by the merciless and monstrous gravitational pull of Jupiter and now its nucleus was fragmenting in response to its precarious approach to the gas giant's limbs. It's thought that in July 1992, at an altitude of only 25,000 kilometres (16,000 miles) over Jupiter's cloud tops and cutting well within the orbit of its innermost moon (Metis), the tidal forces got heavy-handed on the comet's delicate structure and began to rip it apart. Experts speculated that the comet had been caught around 20 to 30 years previously, so Shoemaker-Levy 9 had done well to stay in shape up until this point.

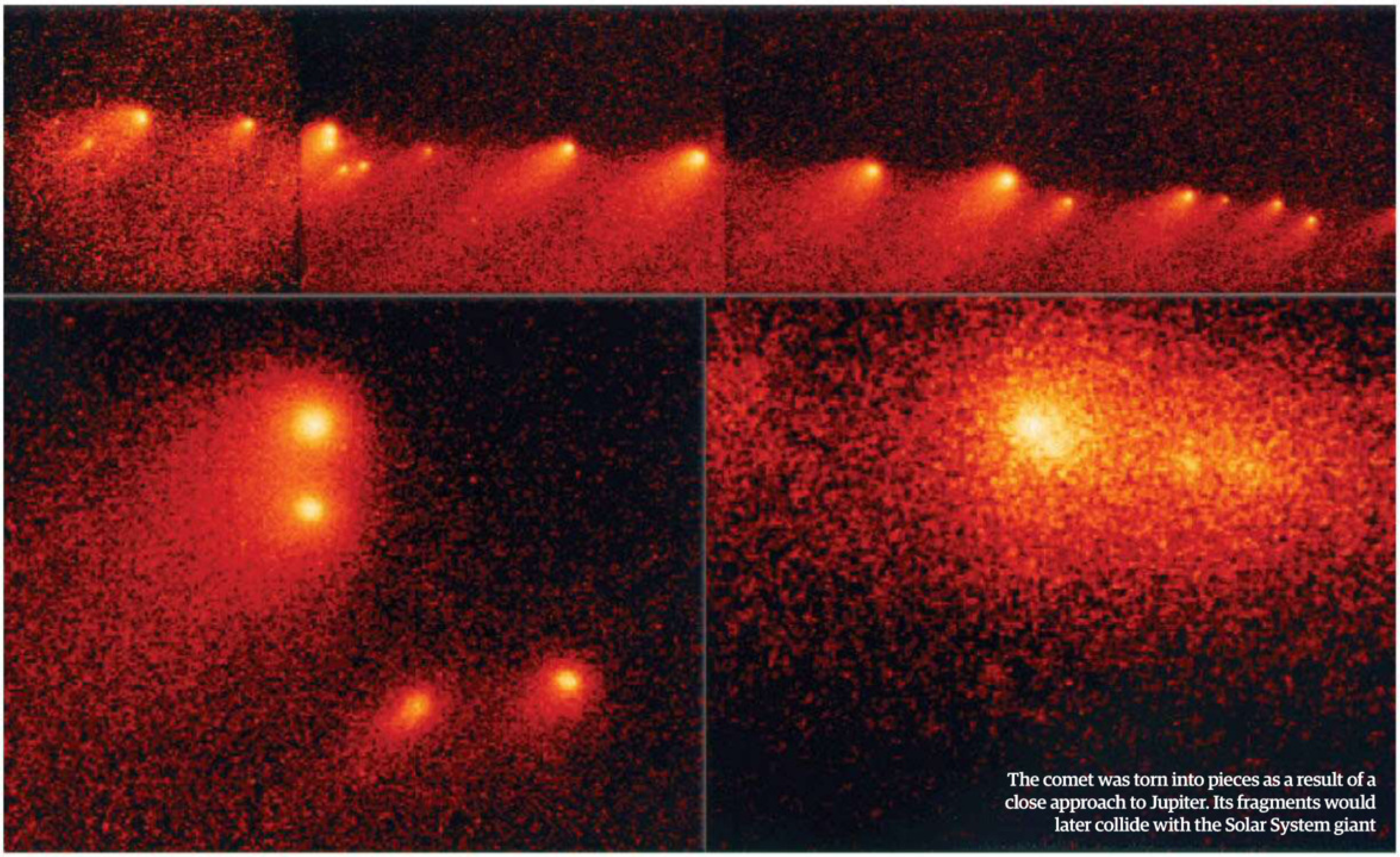
On 22 May, the same year of their discovery, Levy and the Shoemakers would learn of their comet's fate: Shoemaker-Levy 9 was going to end its life by diving into Jupiter's atmosphere. It would impact the planet in many pieces, ranging from a few hundred metres all of the way up to two kilometres (1.2 miles) in diameter. As soon as they found out there was going to be a collision, the three comet-watchers knew it would be a historic comet.

This point of view wasn't shared by all astronomers, however. Some considered Shoemaker-Levy 9 to be a kind of celestial dud and that it was being over-hyped, simply because Jupiter is hit by

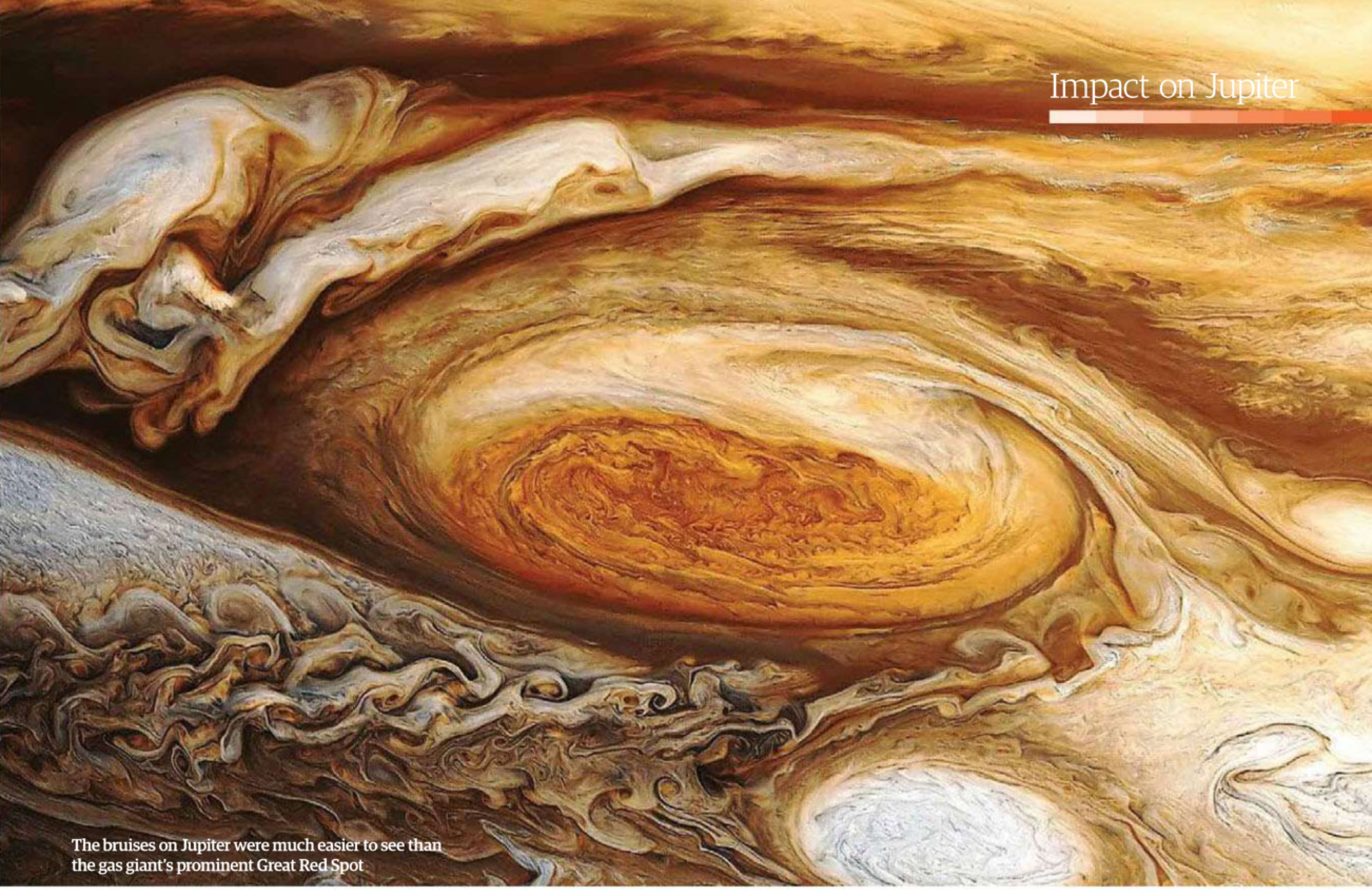


Data from ESA's Herschel Space Observatory showing the Shoemaker-Levy 9 impact could explain why Jupiter has so much water in its upper atmosphere

"The dark spots left across the face of Jupiter were plain to the eye and even more prominent than the planet's famous Great Red Spot"



The comet was torn into pieces as a result of a close approach to Jupiter. Its fragments would later collide with the Solar System giant



The bruises on Jupiter were much easier to see than the gas giant's prominent Great Red Spot

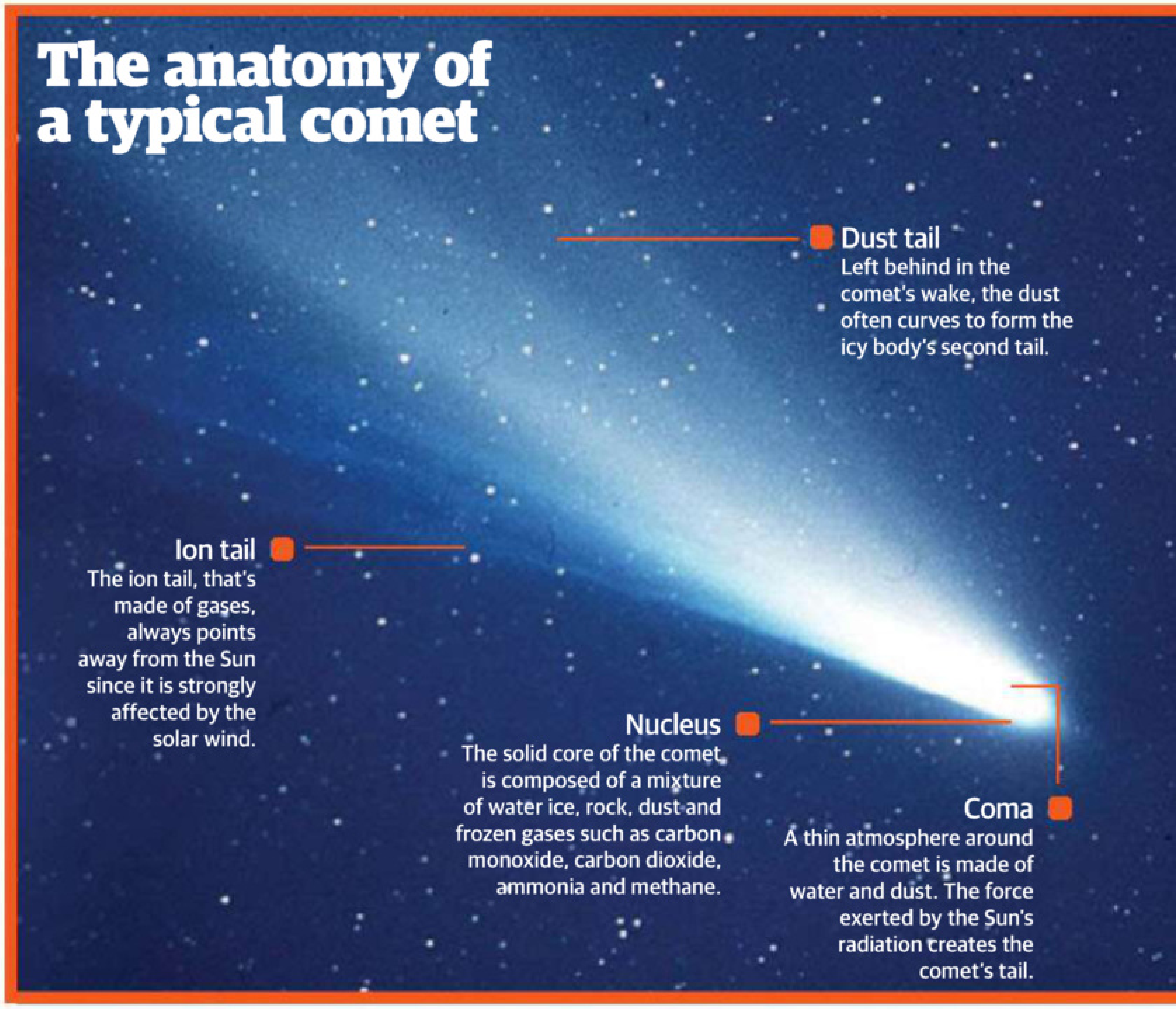
objects all the time, yet nothing happens. What they didn't reckon on was the size of this 'dud': nothing the scale of this fragmented comet had ever hit the gas giant within human memory.

Despite the scepticism, the majority of the astronomical community was watching with bated breath as July the following year arrived. This was the month the various pieces of Shoemaker-Levy 9, labelled fragments A through to W, wheeled in on a path that was destined to hit the giant gas planet's southern hemisphere.

On 16 July 1994, the first fragment crashed in through Jupiter's atmosphere, as telescopes all over the world looked on. Several space-based observatories were also fully focused on the event, such as the Hubble Space Telescope, the ROSAT X-ray observing satellite and also the Galileo satellite, which was on its way to the gas giant at the time. The battering that Jupiter received lasted a whole week, leaving dramatic marks on its surface that made the planet's greatest swirling storm system, the Great Red Spot, pale in insignificance. This iconic feature of Jupiter, for a while, became a second-rate tourist attraction when compared with the trail that Comet Shoemaker-Levy 9 left behind.

Levy himself, by this point, was standing in a long line to the Naval Observatory on the grounds of the American vice president's residence in Washington, hoping to use its telescope to see the impacts his comet had made. When he got in to look through the telescope he was amazed at what he was seeing – the dark spots left across the face of Jupiter were plain to the eye and even more prominent than the planet's famous Great Red Spot.

The anatomy of a typical comet



Dust tail
Left behind in the comet's wake, the dust often curves to form the icy body's second tail.

Ion tail
The ion tail, that's made of gases, always points away from the Sun since it is strongly affected by the solar wind.

Nucleus
The solid core of the comet is composed of a mixture of water ice, rock, dust and frozen gases such as carbon monoxide, carbon dioxide, ammonia and methane.

Coma
A thin atmosphere around the comet is made of water and dust. The force exerted by the Sun's radiation creates the comet's tail.

The planet was so black and blue from the pummelling, that it took close to a year for it to heal. This gave astronomers enough time to work out what extra data the event could yield, that some had previously doubted would be so significant. What lay beneath the cloud tops was revealed when the fragments punched their way through the planet's upper layer at a speed of 60 kilometres (37 miles) per second, like fireballs, ejecting plumes and heating the surrounding jovian gases. The most impressive impact that made the largest mark on the face of Jupiter was fragment G. It created a gigantic dark spot over 12,000 kilometres (7,456 miles) across, and was estimated to have released around the same energy as the world's combined arsenal of nuclear explosives 600 times over. But that's not all that astronomers learned - they also got to know the gas giant much better than ever before.

A closer look at the planet revealed the very first detection of diatomic sulphur, providing only the second finding in any astronomical object, as well as carbon disulphide. Jupiter's make-up was worked out quickly as more molecules such as ammonia were uncovered in the upper atmosphere, while others, such as those carrying oxygen, were nowhere to be seen - much to the surprise of astronomers. A myriad of other molecules were also found much later after the impact, including water in large quantities.

The fragments of Shoemaker-Levy 9 that had bypassed Jupiter's monstrous magnetic field created enormous waves that swept across the planet at speeds of around 450 kilometres (280 miles) per second. Auroral emissions blasted through the gas giant's atmosphere and the planet's temperature raced temperamentally up and down around the impact sites for a good two to three weeks after the event.

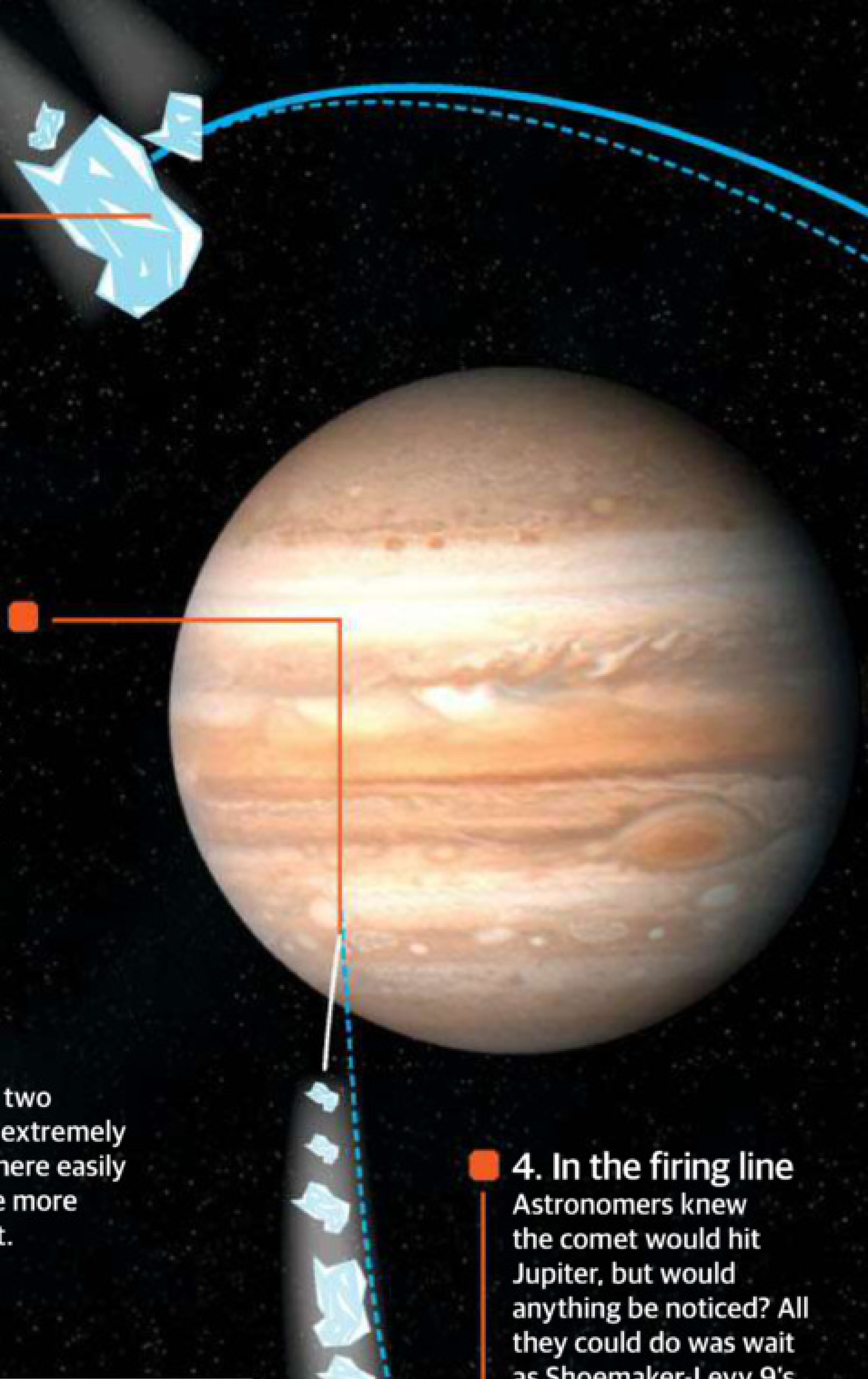
Since the demise of Shoemaker-Levy 9, the tell-tale signs of Jupiter getting struck have not gone unnoticed and have prompted astronomers to keep a close eye on the great planet's next move. Professional and amateur astronomers alike were not disappointed as 2009, 2010 and most recently 2012 saw Jupiter once again take hits. Bolides and asteroids crashed through its upper layer, creating fresh markings that raised the question of whether Jupiter is in fact protecting Earth and keeping us out of harm's way.

The truth is, we just don't know for sure whether or not Jupiter acts as our guardian planet. It could be that the gas giant creates as many potential objects on an apocalyptic trajectory as it sucks up, or maybe its great gravitational attraction has hoovered up the majority of stray comets or pieces of space debris, as it acts as the celestial goalkeeper.

Whatever the role Jupiter currently plays in the Solar System, astronomers will continue to track and observe comets, just like David Levy and Carolyn and Eugene Shoemaker did. Detection for the smaller objects might prove more difficult and in the case of Russia's Chelyabinsk meteorite last year, too late to warn any populated region in its path. Nonetheless, we're learning more and more about these events with every fresh observation, improving our chances of detection in the future and making the world aware that, while Earth is a much smaller target than Jupiter, it's still a viable target in the Solar System's shooting gallery. ■

Impact Jupiter: sequence of events

Follow the path of Shoemaker-Levy 9 - from its discovery through to its plunge into Jupiter's atmosphere

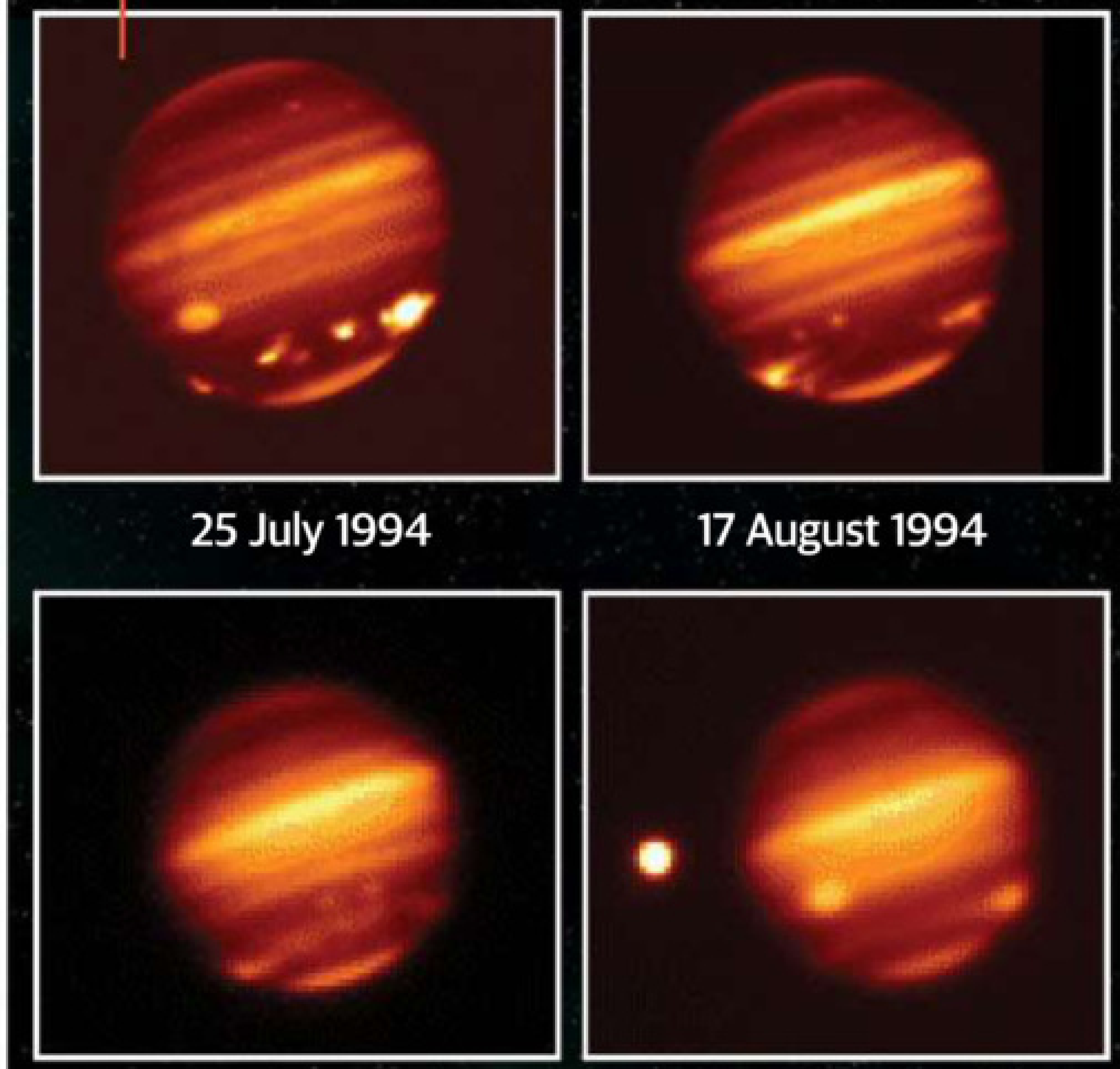


1. Feeling the force (8 July, 1992)
Shoemaker-Levy 9 is likely to have been captured by Jupiter around 20 to 30 years before its discovery. Calculations revealed that its unusually squashed and fragmented form is likely to have been the result of a close encounter with the gas giant's tidal forces in 1992.

5. Impact! (16 to 22 July, 1994)
Astronomers trained ground and space telescopes on Jupiter as fragment after fragment met Jupiter's atmospheric gas between 16 and 22 July.

6. Battered and bruised
The aftermath of the collision between the two significant Solar System bodies left Jupiter extremely bruised, with marks in its southern hemisphere easily picked up by ground telescopes. They were more noticeable than the planet's Great Red Spot.

4. In the firing line
Astronomers knew the comet would hit Jupiter, but would anything be noticed? All they could do was wait as Shoemaker-Levy 9's fragments got closer to the planet.



25 July 1994

17 August 1994

20 September 1994

24 September 1994

Using the MAGIC infrared camera at the German-Spanish observatory on Calar Alto in Spain, astronomers tracked the impact sites over two months after Shoemaker-Levy 9's fragments smashed into Jupiter

Galileo made the only direct observations of Shoemaker-Levy 9

Shoemaker-Levy 9's fragment impact times

Fragment: A
Date: 16 July 1994
Time (UTC): 20:11

Fragment: B
Date: 17 July 1994
Time (UTC): 02:50

Fragment: C
Date: 17 July 1994
Time (UTC): 07:12

Fragment: D
Date: 17 July 1994
Time (UTC): 11:54

Fragment: E
Date: 17 July 1994
Time (UTC): 15:11

Fragment: F
Date: 18 July 1994
Time (UTC): 00:33

Fragment: G
Date: 18 July 1994
Time (UTC): 07:32

Fragment: H
Date: 18 July 1994
Time (UTC): 19:32

Fragment: J
Date: 19 July 1994
Time (UTC): Unknown

Fragment: K
Date: 19 July 1994
Time (UTC): 10:21

Fragment: L
Date: 19 July 1994
Time (UTC): 22:17

Fragment: M
Date: 20 July 1994
Time (UTC): Unknown

Fragment: N
Date: 20 July 1994
Time (UTC): 10:31

Fragment: P2
Date: 20 July 1994
Time (UTC): 15:23

Fragment: P1
Date: 20 July 1994
Time (UTC): Unknown

Fragment: Q2
Date: 20 July 1994
Time (UTC): 19:44

Fragment: Q1
Date: 20 July 1994
Time (UTC): 20:12

Fragment: R
Date: 21 July 1994
Time (UTC): 05:33

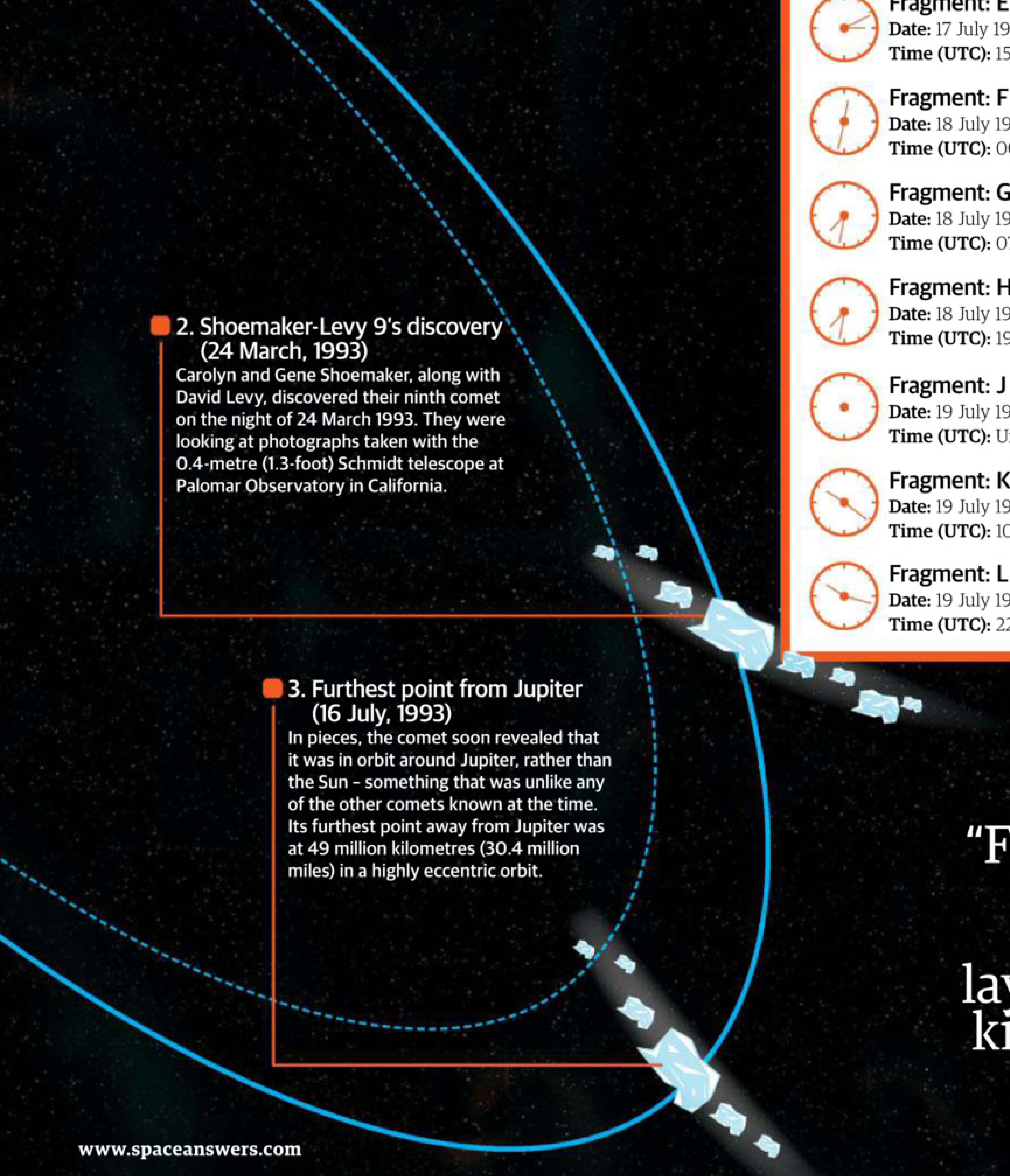
Fragment: S
Date: 21 July 1994
Time (UTC): 15:15

Fragment: T
Date: 21 July 1994
Time (UTC): 18:10

Fragment: U
Date: 21 July 1994
Time (UTC): 21:55

Fragment: V
Date: 22 July 1994
Time (UTC): 04:22

Fragment: W
Date: 22 July 1994
Time (UTC): 08:05



2. Shoemaker-Levy 9's discovery (24 March, 1993)

Carolyn and Gene Shoemaker, along with David Levy, discovered their ninth comet on the night of 24 March 1993. They were looking at photographs taken with the 0.4-metre (1.3-foot) Schmidt telescope at Palomar Observatory in California.

3. Furthest point from Jupiter (16 July, 1993)

In pieces, the comet soon revealed that it was in orbit around Jupiter, rather than the Sun – something that was unlike any of the other comets known at the time. Its furthest point away from Jupiter was at 49 million kilometres (30.4 million miles) in a highly eccentric orbit.

> "Fragments punched their way through the planet's upper layer at a speed of 60 kilometres (37 miles) per second"

© ESA; NASA; SPL

Discovering the comet

Astronomer David Levy was immortalised for his co-discovery of Shoemaker-Levy 9, whose impact on Jupiter 20 years ago held the world in awe

Interviewed by Gemma Lavender

David Levy

Astronomer and writer David Levy has discovered over 20 comets and written 30 books. He has won several awards including the Amateur Achievement Award of the Astronomical Society of the Pacific.

Hubble astronomers watch the first impact of Comet Shoemaker-Levy 9 in July 1994

Could you explain how you found Comet Shoemaker-Levy 9?

Well, I'll try to do it briefly. We [Levy, Gene and Carolyn Shoemaker] have been observing together for a number of years as part of a program to discover comets and asteroids that could pose a threat to the Earth at some time. We never expected to find this guy.

On the night of 23 March 1993 we were observing and actually taking photographs through patchy clouds – it was just before a major weather disturbance. We got our work very much done and taken care of, when Carolyn was scanning the images that we took that night and she found what she felt was a squashed comet. It was on two of the photographs that Gene and I had taken and it was named, as is customary for the discoverers, Shoemaker-Levy 9. That is the short version of how we discovered the comet.

When you discovered that the comet would collide with Jupiter, did you realise it would be such a historic event?

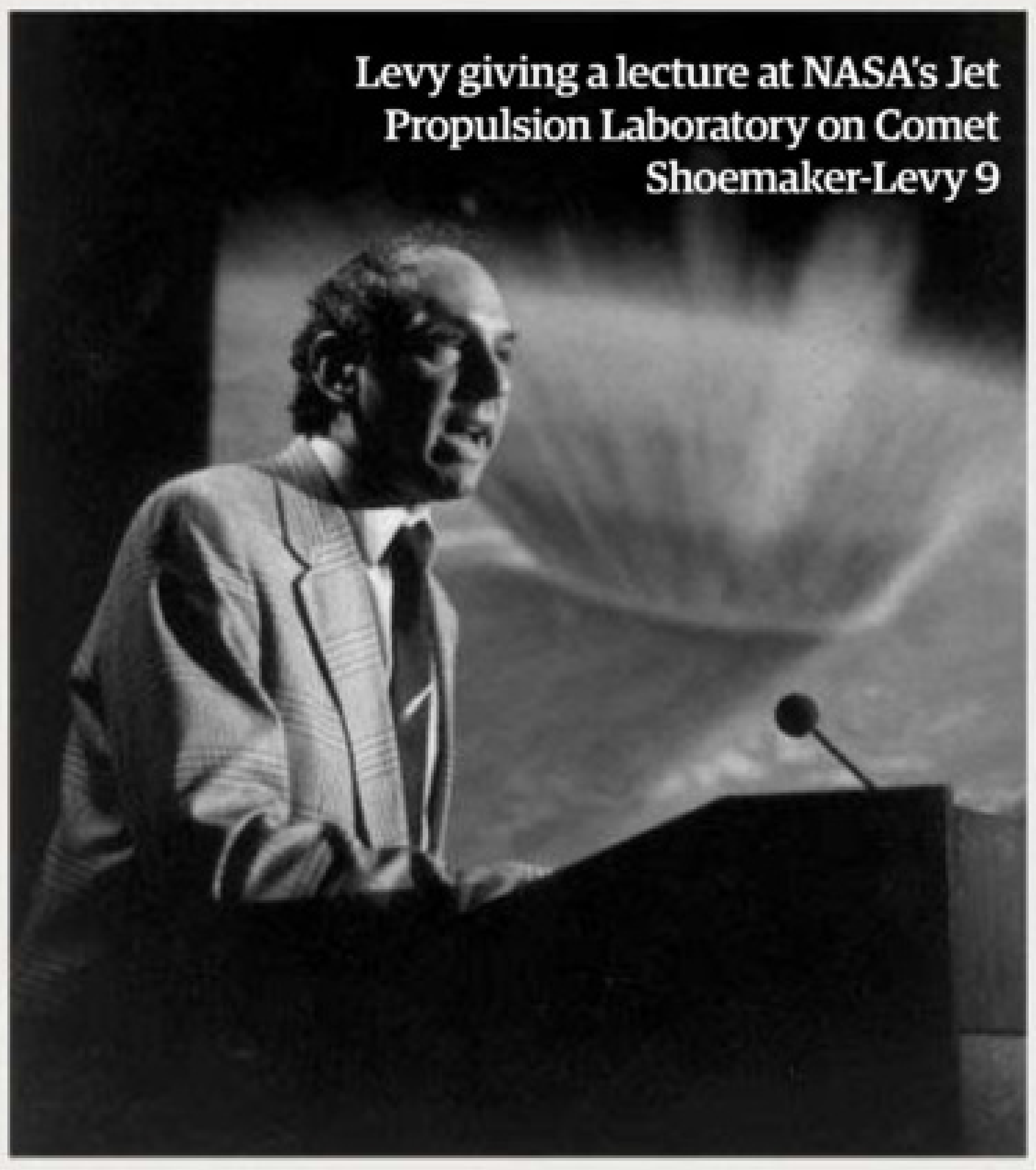
The answer is yes. We knew as soon as we found out that there was going to be a collision (we found that out on 22 May 1993) that this would be a historic comet. But right away everybody started squealing and yelling that we wouldn't see anything, you know, it would be a dud because things hit [Jupiter] all of the time and we never see anything.

What we didn't realise was that apparently nothing that size had collided with Jupiter within the memory of humanity. The spots that were formed were clearly the darkest and most obvious formations to ever be seen on the gas giant. We started seeing them immediately after the first impact and when the other pieces collided, they left spots that were even bigger.

The largest [impact] was left by the fragment known as G and this turned out to be the most obvious feature ever to be seen on the planet Jupiter since the invention of the telescope.

You said that some were sceptical of whether we'd see the impact – would you be able to explain a bit more about that?

[Astronomers] knew it would make an impact, but what they weren't certain about was whether even the Hubble Space Telescope would notice anything. So, we had everybody looking just in case we saw something and boy, did we ever see something!



Levy giving a lecture at NASA's Jet Propulsion Laboratory on Comet Shoemaker-Levy 9

Once the impact was eventually over, did it exceed your expectations?

It exceeded them by a huge amount. I remember that – a few days into the collisions – the Naval Observatory was open to the public on the grounds of the vice president's residence in Washington. I remember standing in a long line and people were encouraging me to go forward, I didn't want to, but I did. I finally got in to look through the telescope after about an hour and I was just amazed at what I was seeing – really dark black spots across the entire face of Jupiter. They were so easy to see and so clear and obvious, I could even see them through the telescope's finder.

Do you think an event like this could happen again in the future?

Oh, it already has happened in fact, but not to the same extent. In 2009, I believe, there was a single small object that collided with Jupiter and left a small spot that lasted for a few days – by the way, the Shoemaker-Levy 9 spots lasted for almost a year. Then I think the following year there was another collision, which didn't leave a spot so this is happening a lot more than we thought it would be – although not quite as obvious as a comet that could be discovered in advance of the collisions, as ours was.

You have obviously been observing comets for a very long time, has this particular impact taught you something new about them?

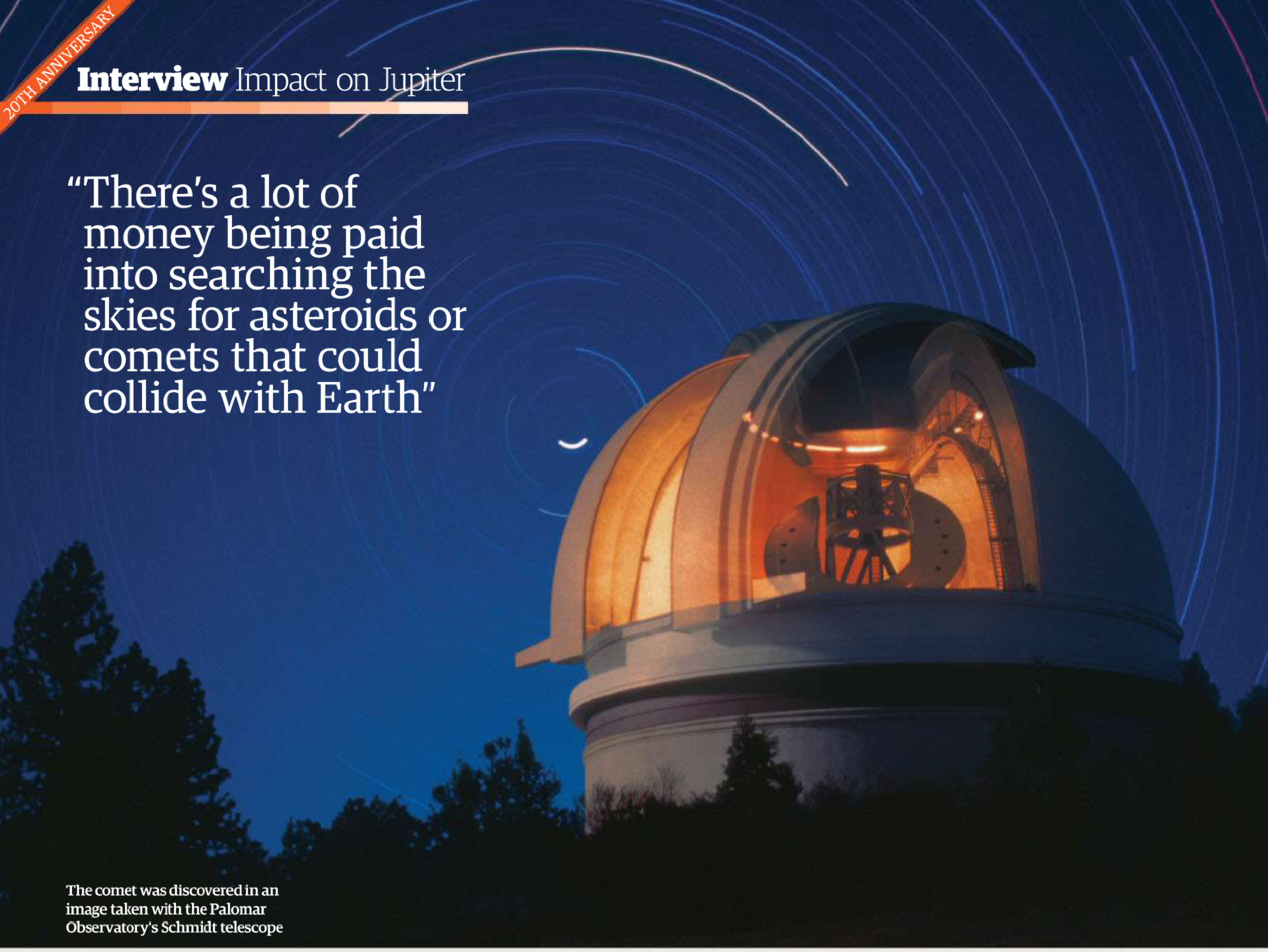
I have been observing and studying comets ever since I was a child. I never actually thought of the idea that comets could collide with a planet – with such an effect. Shoemaker-Levy 9 taught us the basic lesson that comets hit planets and they have dramatic effects. It is possible that in the early days of our planet, comets colliding with Earth could have brought the building blocks of life to our planet. The simple blocks of life – hydrogen, oxygen and nitrogen particles – that would eventually become amino acids and, after that, RNA and, long after that, DNA – the essential building block of life.

Did Shoemaker-Levy 9 change your life? How did you cope with the media reaction?

It was so interesting to be on the front pages of all of the newspapers for a whole week… and all of the TV stations. I remember sitting at NASA headquarters the day before the impacts, being interviewed by maybe 15 to 20 different television stations, one after the other. Then, in the middle of the impacts, I was interviewed again by television stations one after the other. That was really quite an experience. It was something that we felt

> "It was so interesting to be on the front pages of all of the newspapers for a whole week"

“There’s a lot of money being paid into searching the skies for asteroids or comets that could collide with Earth”



The comet was discovered in an image taken with the Palomar Observatory’s Schmidt telescope

was causing the world to pause for a moment. To pause from its preoccupation, the normal buzz of the nightly newscast, and [kind of] look up into space for a moment and contemplate the vastness of the universe, as well as the role of humanity in that universe.

You know, we thought that there were more stars in our galaxy than there are grains of sand on a beach, as well as more galaxies in the universe than there are grains of sand on all of the beaches of the world. Despite that, there is only one of you and only one of me in the entire universe.

How did start working with the Shoemakers?

Before I wanted to work with them, I had already built up a reputation as a comet-discoverer, having found, I believe, four comets when I met them. I arranged for the Shoemakers to observe at a telescope near Tucson one night – they wanted to try it out.

On the way down from that observing session, I looked back at them and said: “I have something to ask you, but I’m a little afraid to do it.” Gene said: “Well the best way to do it is to just look at us and out with it.” I said “Okay, I would like to observe with you at Palomar. Is that a possibility?” Gene and Carolyn looked at each other and looked seriously and critically and Gene laughed and said: “I think that would be possible.” I started [observing] with them about six months later and observed with them from the late summer of 1989 all of the way until the end of 1994 and then we had one final session in the spring of 1996.

How hard is it to find a comet? Is it something anyone would be able to do?

It’s very difficult especially now, because part of what we accomplished with Shoemaker-Levy 9 was to get the world interested in this problem of “is there an asteroid or comet that could collide with the Earth? If there is, we’d better find it.”

Now there’s a lot of money being paid into searching the skies for asteroids or comets that could collide with the Earth. We have actually found a couple within a few hours of their collisions with us – not comets, but small asteroids. We missed the one that hit Russia a few months ago… because it was very close to the Sun as it was approaching us and we never got to see it and finally it collided with us very, very rapidly. It didn’t do any damage, except a lot of broken windows and the scratches that people got. I don’t think there were any fatalities and I think everybody was okay, but it did teach us that Earth is a target and we will be hit again. Let’s hope we’re not hit by any of the big kinds.

How would we raise the alarm if an asteroid were heading our way?

The person who is in charge of that right now is a man named Donald Yeomans and he is at [NASA’s] Jet

Levy was working alongside Gene and Carolyn Shoemaker (pictured) when they discovered Comet Shoemaker-Levy 9. The astronomers discovered over ten comets

Propulsion Lab in Pasadena, California. He keeps track of all the orbits of the asteroids and comets in the sky. If he finds one that is discovered early and it could be on a collision course with the Earth, he does alert the world leaders about it.

That happened once, about a day before there was going to be an impact I think, in the Sudan. He informed the White House immediately and they informed the Sudanese that this is going to be happening and they wanted to know if this would be a natural thing or a nuclear detonation. They were able to assure them that this would be a natural object coming out of the sky and that it shouldn't hurt [them] but it is going to land over [their] country.

What equipment do you use to locate comets?
I do it in two ways – first with my eye and a 16" reflector telescope, but I also take electronic images with five or six other telescopes at the same time. It takes me about an hour to get those telescopes up and going and once they are, I then can relax and do the visual search and that's a lot of fun. There's a lot of attention that is needed to set up the automated cameras, but once they are up and running, it's a beautiful thing for me to be just sitting back with the telescopes and watching the sky for comets. I search the sky by one field of view per second and just move the telescope slowly across the sky towards the east and I enjoy that very much.

There was a famous astronomer who wrote a book about his own life with comets and he said, and I quote: "I have watched a dozen comets, hitherto unknown, slowly creep across the sky as each one signed its sweeping flourish in the guest book of the Sun". That astronomer was named Leslie Peltier and is one of the most beautiful things I have ever heard about comets.

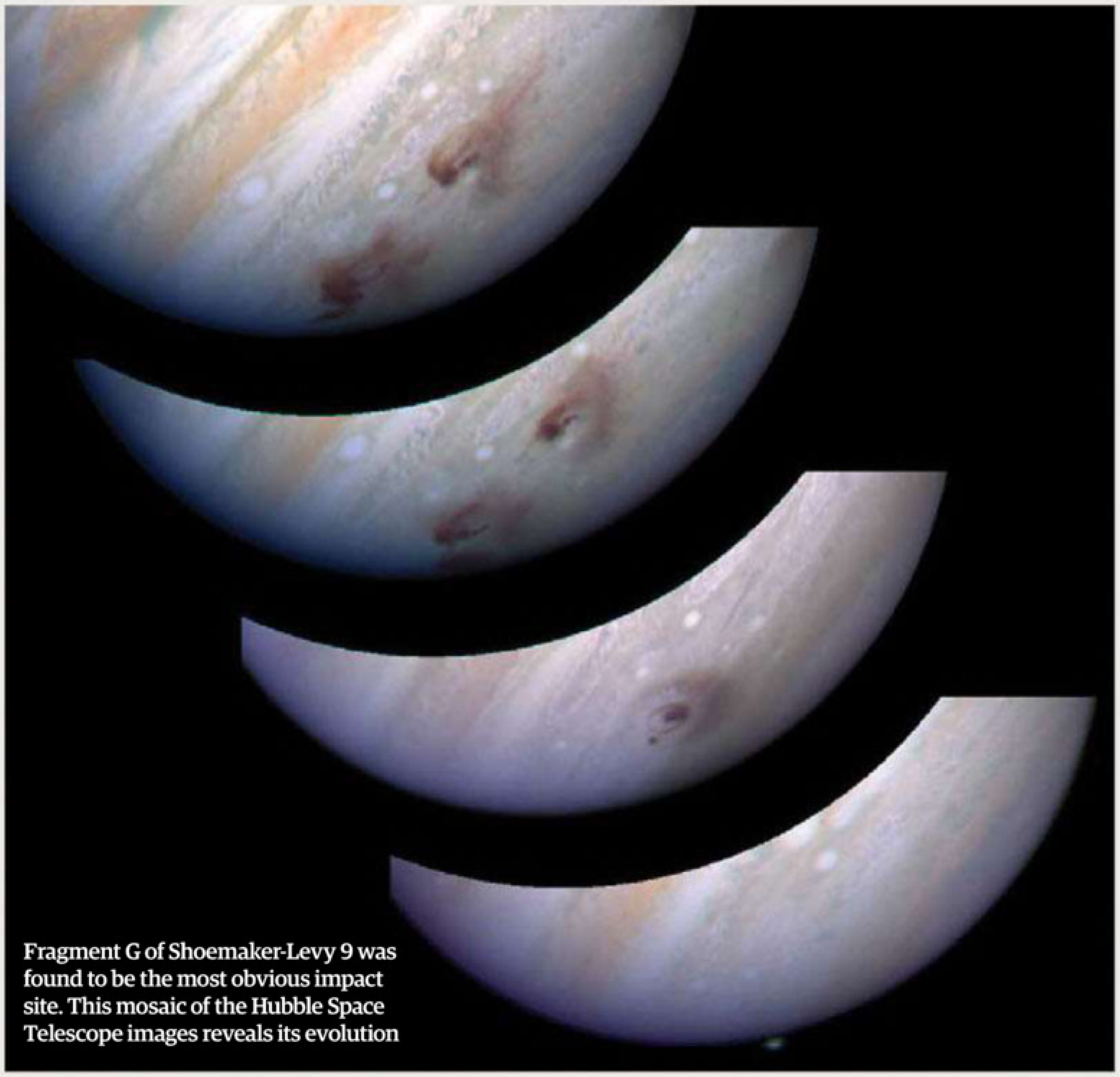
Do you do your observations every night?
Not tonight because there's a full Moon, but when the Moon is not in the sky, I'm usually observing for at least the hour before dawn in the morning and I will be starting again in about a week to ten days' time.

What's the faintest comet you have ever found?
The faintest one I found was located electronically, it's credited partly to me but it was actually found automatically by one of our telescopes here at the observatory. Because of that little trick it was not named for us as its discoverers, but it was named for the observatory, so that comet is known as Comet Siamak. Other examples of comets named after observatories is Comet ISON, of course, which totally disintegrated before it had the chance to become bright.

What are some of the other Shoemaker-Levy comets like?
We found a total of 13 of them together. Nine of them are in orbits that have them coming back again and again, and they are called periodic comets. Of course, the ninth won't come back again because it has collided with Jupiter and is deceased now. We found four others that are not periodic and they just came across once and never again. So that's thirteen comets plus eight that I have discovered myself from my home here, from my telescope and using just my eye and an eyepiece at the telescope... The most recent comet I found that way, visually, was in October 2006, so it's been a long time but I'm still looking. ■

An artist's impression illustrating the breakup of the comet

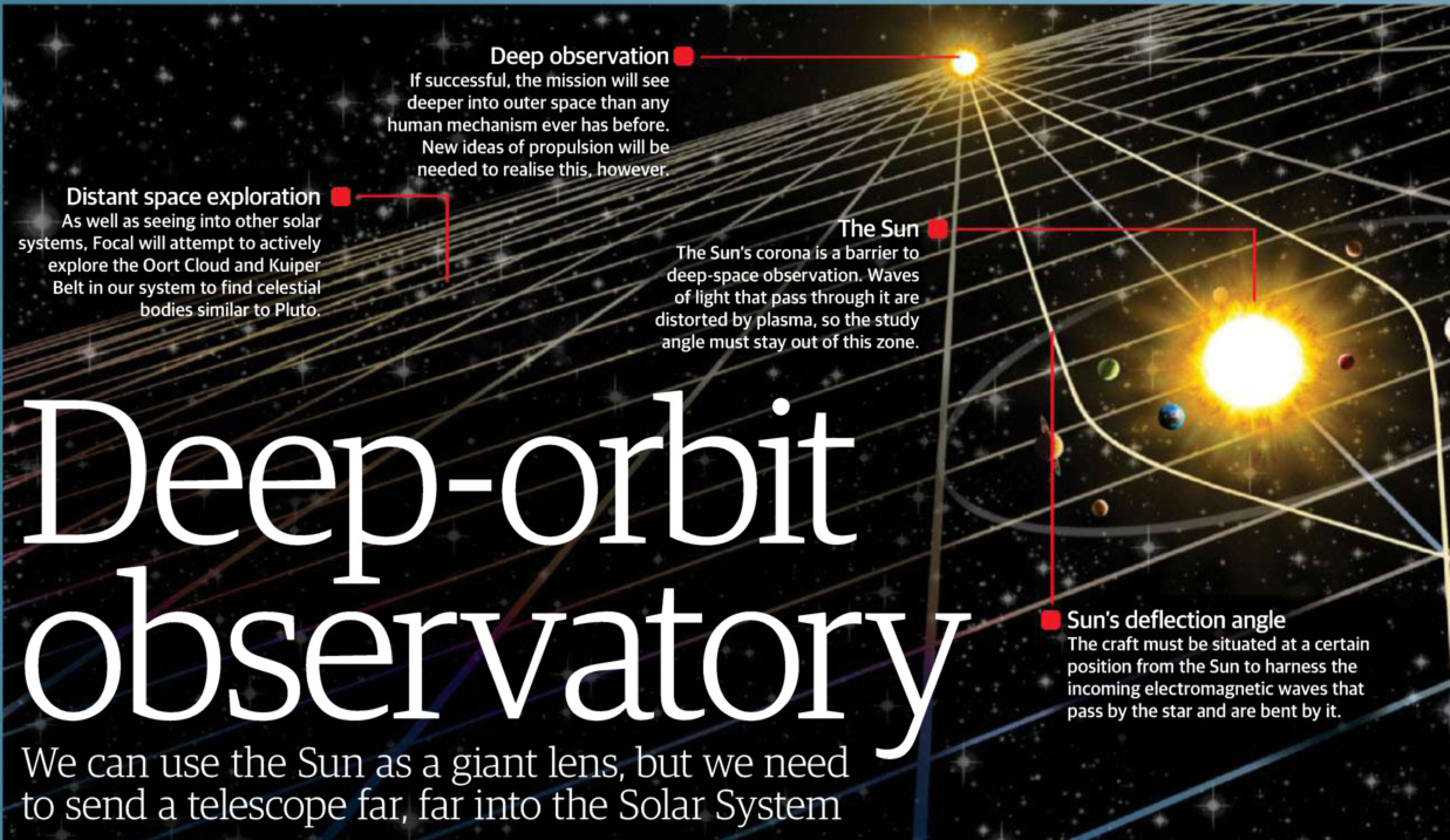
"It's a beautiful thing for me to be just sitting back with the telescopes and watching the sky for comets"


Fragment G of Shoemaker-Levy 9 was found to be the most obvious impact site. This mosaic of the Hubble Space Telescope images reveals its evolution

© Science Photo Library; NASA; NASA/JPL

Deep-orbit observatory

We can use the Sun as a giant lens, but we need to send a telescope far, far into the Solar System



Deep observation
If successful, the mission will see deeper into outer space than any human mechanism ever has before. New ideas of propulsion will be needed to realise this, however.

Distant space exploration
As well as seeing into other solar systems, Focal will attempt to actively explore the Oort Cloud and Kuiper Belt in our system to find celestial bodies similar to Pluto.

The Sun
The Sun's corona is a barrier to deep-space observation. Waves of light that pass through it are distorted by plasma, so the study angle must stay out of this zone.

Sun's deflection angle
The craft must be situated at a certain position from the Sun to harness the incoming electromagnetic waves that pass by the star and are bent by it.

Using a technique called gravitational lensing, the Focal Mission will enable us to see deeper into space than ever before. With the ability to view distant objects at a huge magnification, the telescope will be situated between 550 and 1,000 AU from the Sun, which is the greatest area of magnification possible.

Originally devised by SETI astronomer Claudio Maccone in a 1992 paper, Focal was formally proposed to the European Space Agency in 2000 and put forward by Maccone at the International Astronautical Congress (IAC) in 2010.

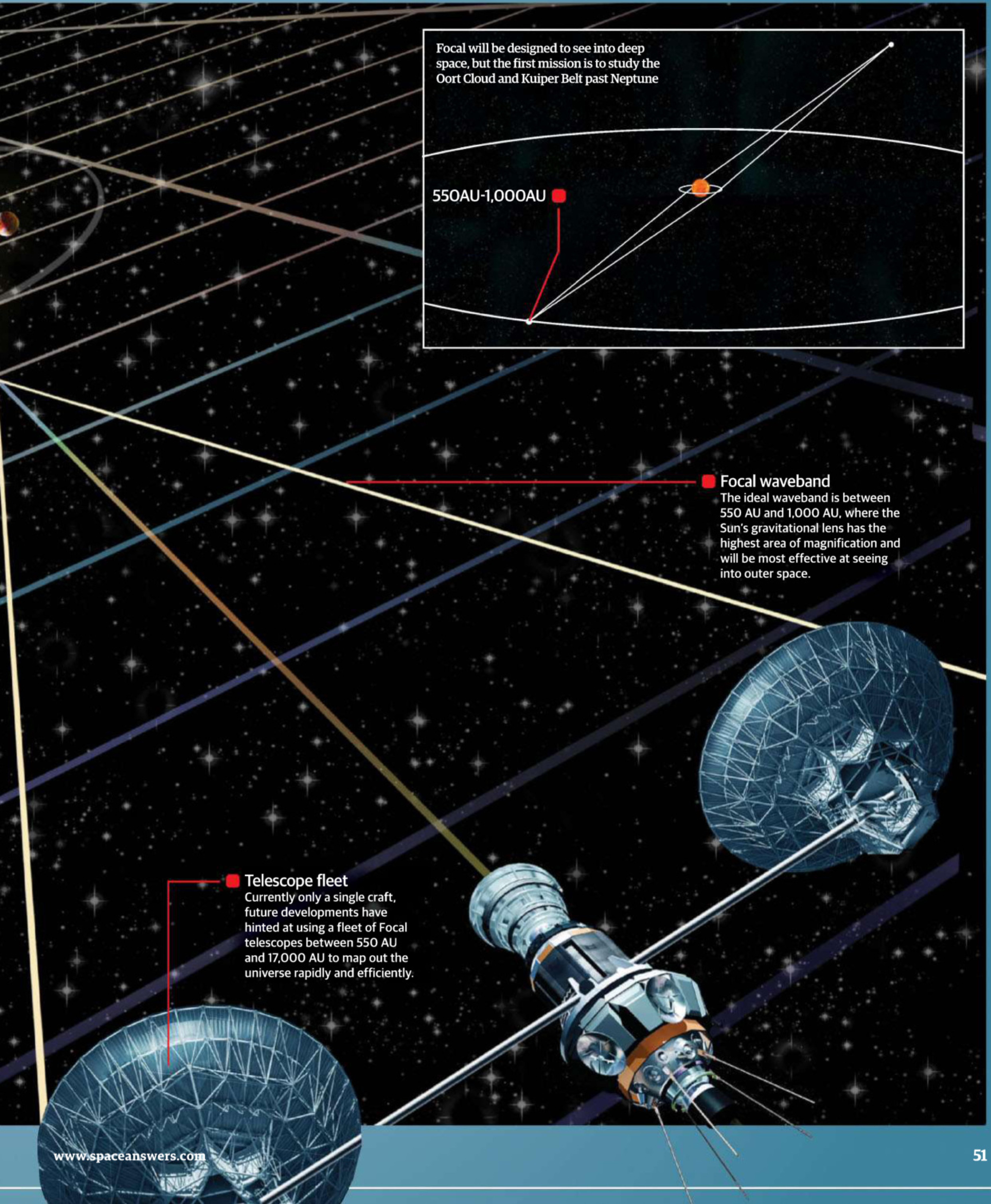
The telescope's magnification works by distorting space-time, an idea that was published in a 1936 paper by Albert Einstein using his theory of relativity. This was improved upon first in 1964 by Sidney Liebes' mathematical theory of gravitational focusing and then in 1978 by the discovery of twin quasars by astronomer Dennis Walsh. It is essential that the Focal probe's motion is studied within the context of special relativity, not classical Newtonian mechanics. This is because, unlike Newton's teachings, Einstein explains that gravity can alter the direction of light and cause the lensing effects that will be so important to Focal.

The probe must be sent in the opposite direction of the system we want to observe. This is to view the deflection angle created by incoming electromagnetic waves that pass outside the Sun, but within a certain distance of its centre. These are ideal for the Focal spacecraft to use as a lens to see into the outer reaches of space.

If we could harness the Sun's gravitational lens, we would be able see into the early universe and distant exoplanets in systems like Alpha Centauri. Two of Focal's key targets include the Kuiper Belt and the Oort Cloud. Evidently, new systems of propulsion will have to be achieved to realise Focal, as the estimated distance to travel will be 14 times the distance from the Sun to Pluto.

The Focal spacecraft will use either a nuclear-powered electric propulsion (NEP) system, a xenon-fuelled ion engine or an advanced type of solar power, as the velocity relative to Earth would have to be 100 kilometres (62 miles) per second to reach a distance of 1,000 AU in 50 years. When the craft reaches its set destination, it will assess parallax distances, map the rotation curve of the galaxy, explain a star's stages of nuclear burning and make carbon stars visible. Focal could use a one-metre (3.3-foot) optical telescope with a ten-Watt laser transponder as an optical communication system that will transmit the data back to a satellite orbiting Earth

A similar programme to the Focal Mission is the Herschel ATLAS project. The ESA-led project, like Focal, will look into the far-infrared and sub-millimetre wavebands of light. Experts are predicting that as many as 250,000 galaxies will be seen in this wavelength. This has led Maccone to claim these projects are "the next most-important target that humankind must reach in order to be prepared for the successive and more-difficult task of achieving interstellar flight".



Focal will be designed to see into deep space, but the first mission is to study the Oort Cloud and Kuiper Belt past Neptune

Focal waveband
The ideal waveband is between 550 AU and 1,000 AU, where the Sun's gravitational lens has the highest area of magnification and will be most effective at seeing into outer space.

Telescope fleet
Currently only a single craft, future developments have hinted at using a fleet of Focal telescopes between 550 AU and 17,000 AU to map out the universe rapidly and efficiently.

© Adrian Chesterman

Billion-dollar telescopes

Larger than any telescope ever developed and capable of peering deep into space, three expensive super structures are set to change our view of the universe forever

Written by David Crookes

There exists a new space race of sorts – a scramble to create the largest and most sophisticated telescopes ever devised. While the 2.4-metre- (7.9-foot-) aperture Hubble Space Telescope may continue to impress as it reveals many secrets of the universe and unblocks further chunks of human knowledge, the extremely large ground-based telescopes that are on the verge of being built will surpass its achievements many times over.

Each of the next-generation telescopes – the European Extremely Large Telescope, the Thirty Meter Telescope and the Giant Magellan Telescope – will be located not in space, but here on Earth in the most desolate regions.

Benefitting from the high altitudes of mountain tops and far from the light pollution of towns and cities, they will be able to gather more than ten times as much light as Hubble. What's more, with the telescopes ranging from 25 to 39.1 metres (82 to 128 feet) in diameter, these massive observatories will be able to detect atoms and molecules that are several light years away, giving us glimpses of the universe like never before.

These telescopes follow the scientific line set by Galileo and Newton, but are attempting to redefine the rules. In the history of telescope-building, each generation has been roughly twice as large as the previous. The eight- and ten-metre (26- and 33-foot) telescopes we see around today followed four-metre (13-foot) telescopes – they in turn had followed two-metre (6.6-foot) devices.

The drive for new optical technologies has only intensified as the years have rolled by. So, while Jodrell Bank Observatory in the UK heralded the invention of radio-astronomy in Europe in 1945, and the first space telescopes opened up new regions of electromagnetic spectrum, astronomers have wanted to leap ahead quicker than ever before. It's certainly no accident that the E-ELT in particular advances by a factor of four – the team would have gone bigger if they could.

Of course, this is a good thing, and there's no question that larger telescopes are needed – they will satisfy a desire by a huge numbers of scientists to open new frontiers. The only major issue, given the advances that will be made, is whether the world should actually be creating more. But that's a topic of debate for another time.

Europe's window to the universe is extremely large

Set for completion in 2024, the E-ELT Telescope will see with a stunning 15 times the detail of the Hubble Space Telescope

INTERVIEWBIO

Dr Joe Liske
European Southern Observatory

On top of Cerro Armazones, deep in the Atacama Desert in northern Chile, a new feature is set to dominate the landscape over the next decade. Sitting 20 kilometres (12.4 miles) from the Paranal Observatory, the European Extremely Large Telescope (E-ELT) will, when complete, become the world's largest eye on the sky.

It will enable 15 times more detail than the Hubble Space Telescope and take astronomy to places it has never been before, letting scientists gain insights into the nature of black holes, dark matter, as well as energy and galaxy formation. It will push human knowledge of space forward to unprecedented heights.

Dr Joe Liske, a German astronomer based at the European Southern Observatory, believes this is driving the 14 member states, from Austria to Germany, Sweden to Switzerland and the UK, to throw their weight behind the €1.1 billion (£881 million / $1.5 billion) project. Such is the scale of the project that the first non-European nation, Brazil, is about to become the 15th member.

"Everything about the E-ELT is huge," says Dr Liske. "The mountain is 3,064 metres [10,052 feet] high but we're going to take 18 metres [59 feet] off the top of it to create a platform big enough the hold the telescope. The platform on top of the mountain will be more than 150 metres [492 feet] in diameter, housing a telescope building of 90 metres [295 feet]. Inside the building will be a telescope with a 39.1-metre- [128-foot-] diameter segmented primary mirror. It's going to be quite a sight."

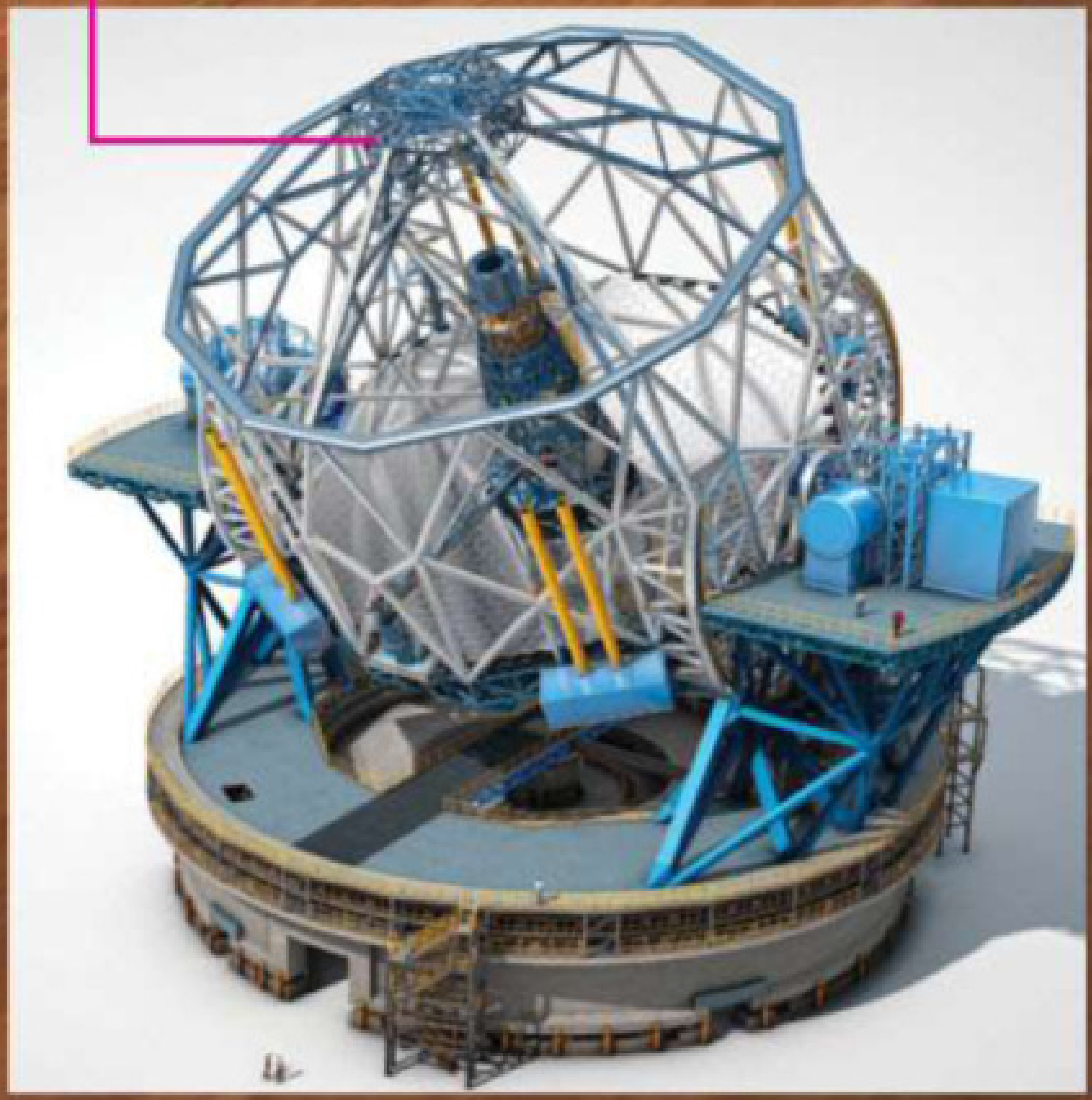
However, it could have been even bigger. "We were studying the possibility of building a 100-metre [328-foot] telescope, which had the great acronym OWL – Overwhelmingly Large Telescope," he laughs. "But it was too expensive and technically too risky. They decided to be modest and go for 42 metres [138 feet] before scaling it slightly back to the current level."

Underpinning the need for a large telescope is the ESO's desire to see Earth-like planets around other stars. Scientists want to study them in enough detail so that they can look for signs that there may be life on one of these planets. Dr Liske says only a telescope of approximately 40 metres (131 feet) will enable astronomers to achieve this to its full potential. "If you go far below this size, then you lose that ability," he explains.

In order to achieve the size scientists need, the telescope itself will be made up of a large set of mirrors rather than a single piece of glass. "You just can't make a single piece of glass 39 metres [128 feet] in diameter," Dr Liske says. The primary mirror is broken into 798 smaller hexagonal segments around 1.42 metres (4.66 feet) across. It's not a pioneering method: the Keck telescopes on Mauna Kea in Hawaii and the Gran Telescopio Canarias, run by Spain on La Palma, are also segmented. "But what we've done with the E-ELT is take this concept of segmenting a primary mirror to a whole new level," continues Dr Liske. "The Keck has 36 segments so ours will be on an entirely different [scale] in terms of controlling the telescope. Each of the segments will be individually mounted and steerable. We'll be able to move them up and down, tilt them around two axes and even change their shape, and this will benefit us because we'll be able to get the best possible image quality out of our telescope."

The huge primary mirror affects the sharpness of the image collected by the telescope. This is fundamental physics, Dr Liske explains, or more specifically optics law. Light is reflected from the primary mirror to four smaller mirrors which in turn direct it to cameras and other interchangeable measuring instruments.

But what makes the E-ELT's large size even more impressive is that it can collect more light than all of the existing eight- or ten-metre- (26- or 33-foot-) class telescopes on the planet put together. "We'll be able to see the same objects as we could see before, only to much greater distances, or at a fixed distance we could see intrinsically fainter objects," Dr Liske explains. "Both of those things are important to astronomers because we want to see further out into the universe." The E-ELT is earmarked for completion in 2024. "It's an exciting time to be involved," Dr Liske says. You cannot fail to agree.

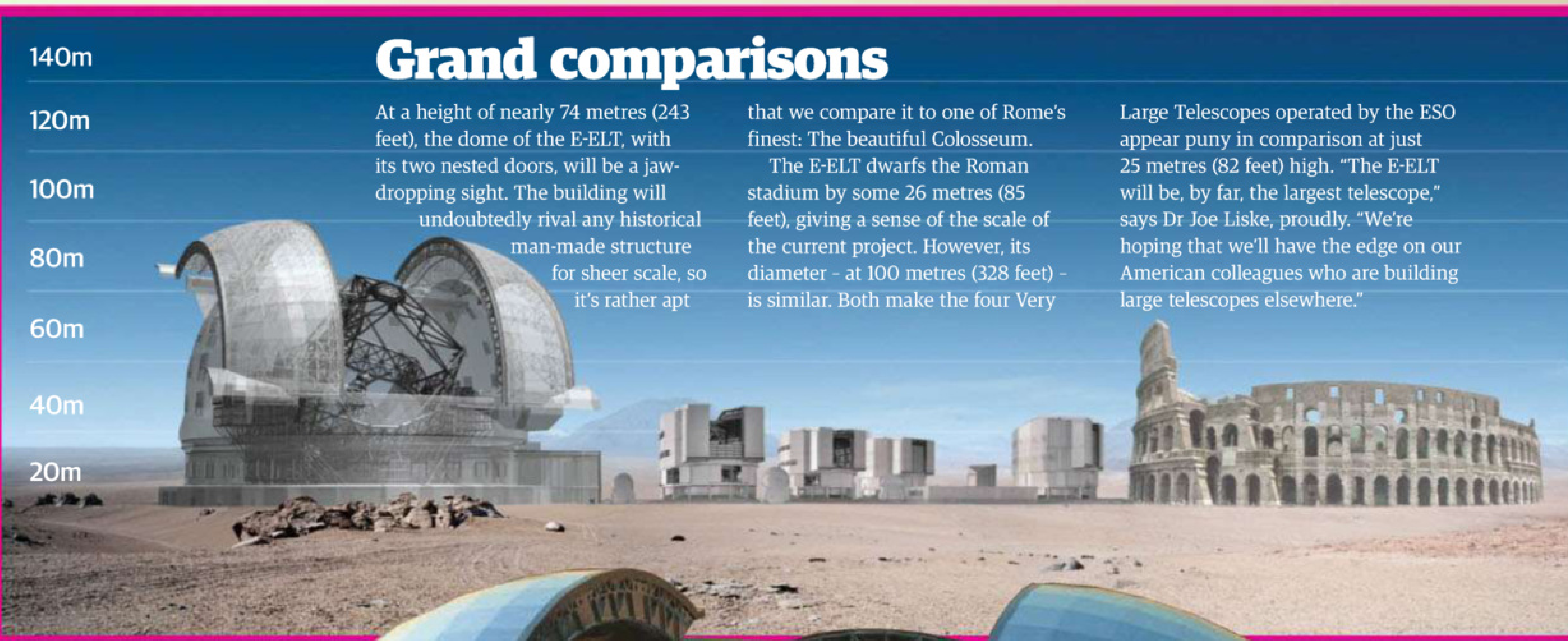


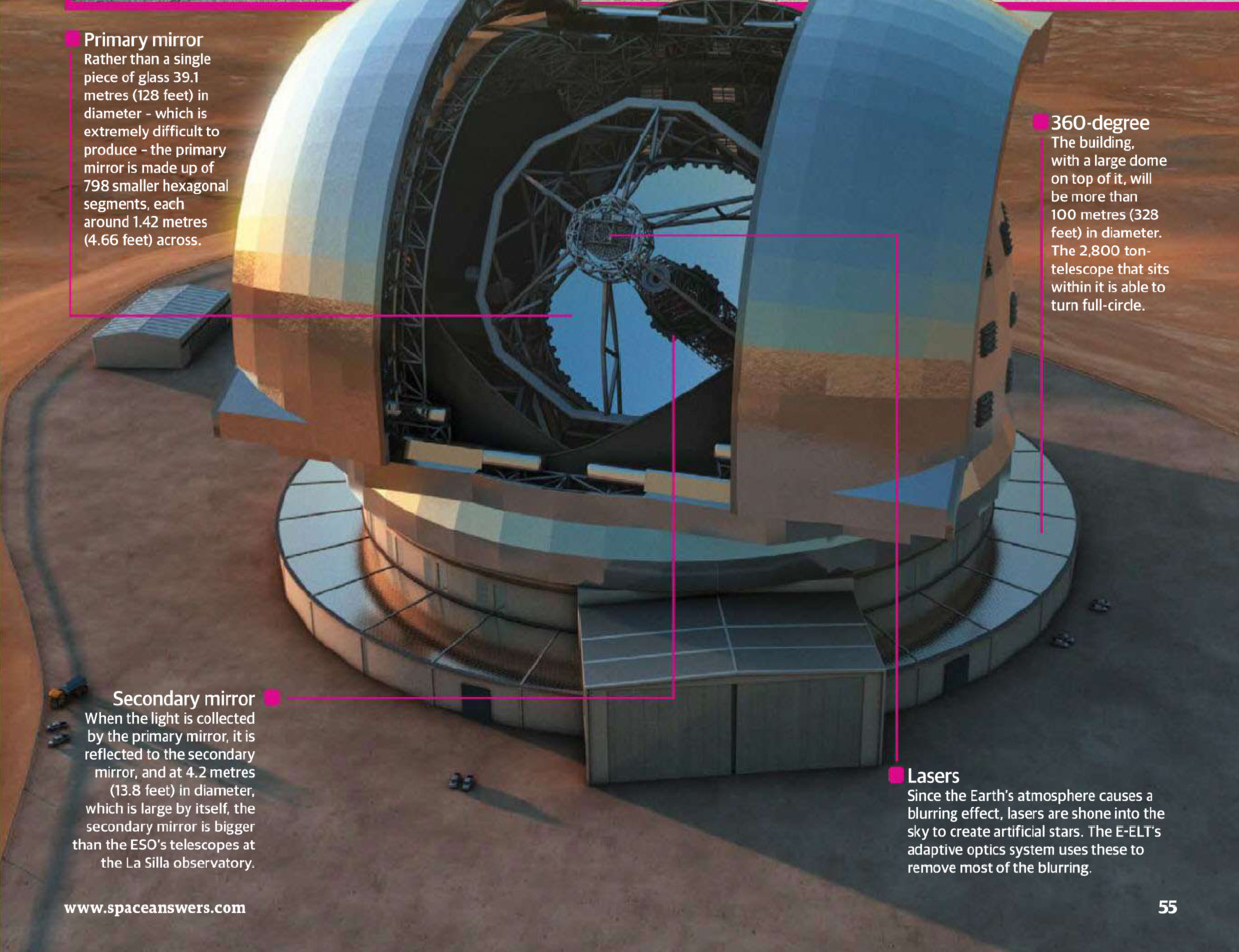
More mirrors
The tubular device in the centre of the telescope contains three more mirrors. One at the bottom relays light to an adaptive mirror above it. Distortions are corrected. A middle mirror stabilises the image.

Grand comparisons

At a height of nearly 74 metres (243 feet), the dome of the E-ELT, with its two nested doors, will be a jaw-dropping sight. The building will undoubtedly rival any historical man-made structure for sheer scale, so it's rather apt that we compare it to one of Rome's finest: The beautiful Colosseum.

The E-ELT dwarfs the Roman stadium by some 26 metres (85 feet), giving a sense of the scale of the current project. However, its diameter - at 100 metres (328 feet) - is similar. Both make the four Very Large Telescopes operated by the ESO appear puny in comparison at just 25 metres (82 feet) high. "The E-ELT will be, by far, the largest telescope," says Dr Joe Liske, proudly. "We're hoping that we'll have the edge on our American colleagues who are building large telescopes elsewhere."





Primary mirror
Rather than a single piece of glass 39.1 metres (128 feet) in diameter - which is extremely difficult to produce - the primary mirror is made up of 798 smaller hexagonal segments, each around 1.42 metres (4.66 feet) across.

360-degree
The building, with a large dome on top of it, will be more than 100 metres (328 feet) in diameter. The 2,800 ton-telescope that sits within it is able to turn full-circle.

Secondary mirror
When the light is collected by the primary mirror, it is reflected to the secondary mirror, and at 4.2 metres (13.8 feet) in diameter, which is large by itself, the secondary mirror is bigger than the ESO's telescopes at the La Silla observatory.

Lasers
Since the Earth's atmosphere causes a blurring effect, lasers are shone into the sky to create artificial stars. The E-ELT's adaptive optics system uses these to remove most of the blurring.

GMT: It's time for the next generation

Featuring the world's most advanced mirrors, impressive defence against the elements and some of best images imaginable

INTERVIEWBIO

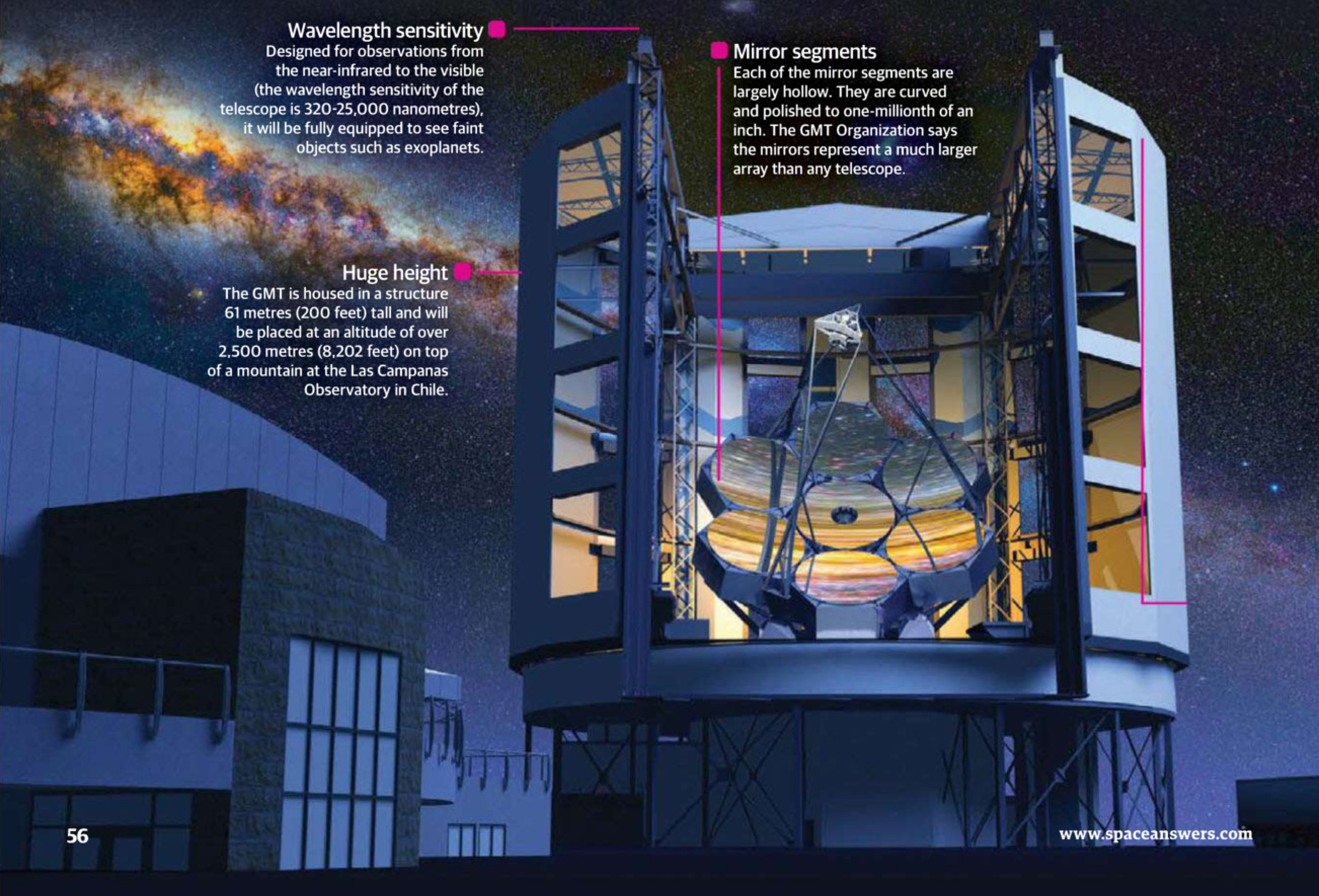
Patrick McCarthy
Director
GMT Organization

The Giant Magellan Telescope will be smaller than the E-ELT but it's by no means inferior. Scientists at the University of Arizona and in California claim it will contain the world's most advanced mirror. What's more, the GMT will contain seven of them.

Work has already started on the telescope. Astronomers have blasted 85,000 cubic metres (3 million cubic feet) of rock from the top of a mountain in the Chilean Andes and this will provide a base for the structure at the Carnegie Institution's Las Campanas Observatory, which is now poised to enter the construction phase.

The idea for the telescope goes back to 2000, when astronomers noted that the large structured mirrors made in Arizona were producing outstandingly good images. "They were producing images that were actually better than we expected," says Dr Patrick McCarthy, director of the GMT Organization. "They performed well mechanically, they're very stiff and they're polished to exquisite precision in Arizona. We learned how to control them on the mountain tops, manage their temperature and adjust their shapes. People then started thinking about the next stage: how we could go from a ten-metre [33-foot] telescope to 20 or 30 metres [66 or 98 feet]."

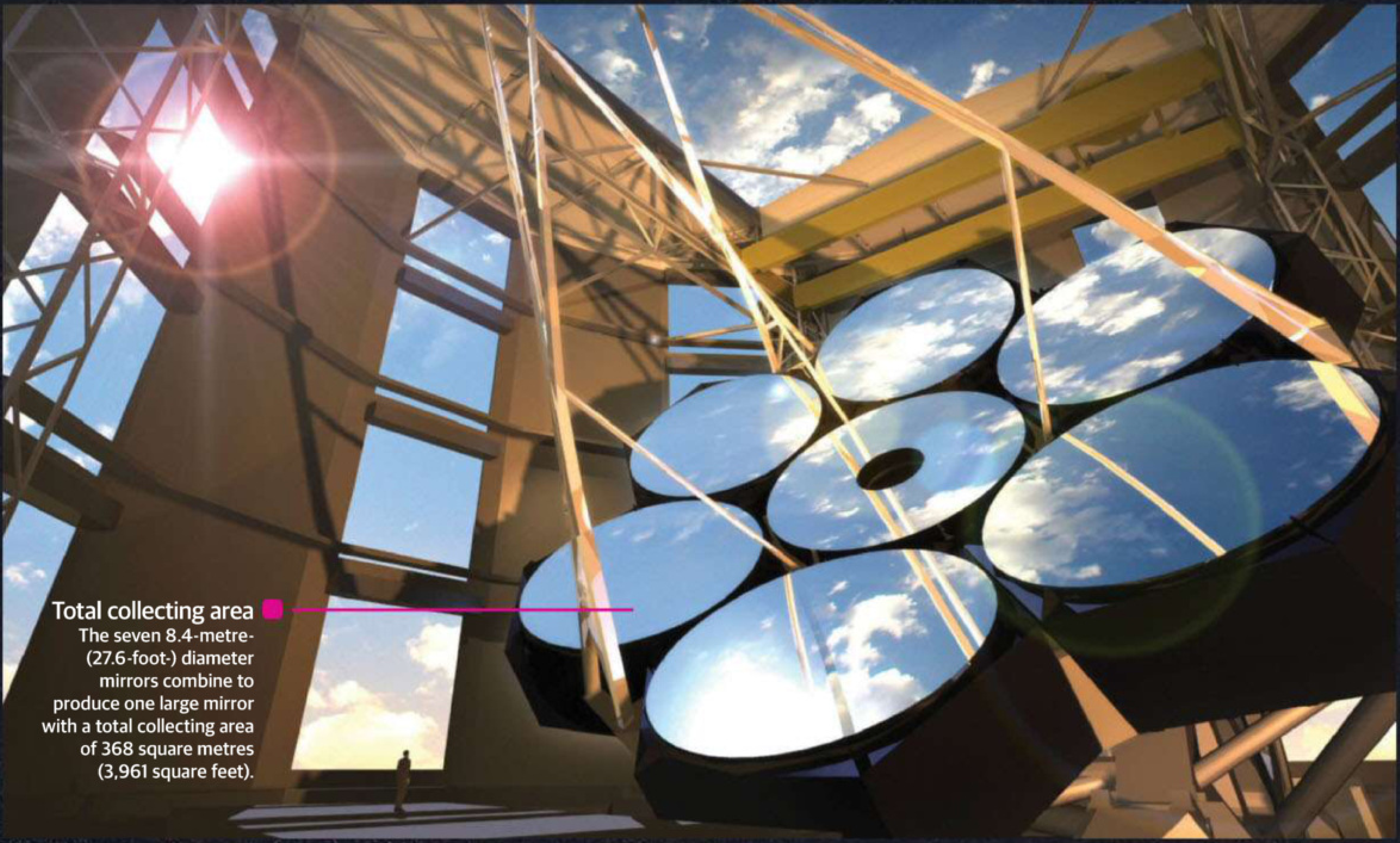
While the primary mirrors of the E-ELT and TMT will be made up of small segments, the GMT takes six 8.4-metre (27.6-foot) mirrors and arranges them off-axis in a lotus petal shape around a central



Wavelength sensitivity
Designed for observations from the near-infrared to the visible (the wavelength sensitivity of the telescope is 320-25,000 nanometres), it will be fully equipped to see faint objects such as exoplanets.

Mirror segments
Each of the mirror segments are largely hollow. They are curved and polished to one-millionth of an inch. The GMT Organization says the mirrors represent a much larger array than any telescope.

Huge height
The GMT is housed in a structure 61 metres (200 feet) tall and will be placed at an altitude of over 2,500 metres (8,202 feet) on top of a mountain at the Las Campanas Observatory in Chile.



Total collecting area

The seven 8.4-metre- (27.6-foot-) diameter mirrors combine to produce one large mirror with a total collecting area of 368 square metres (3,961 square feet).

"It will enable them to collect fantastic images at the most cost-effective price"

mirror, making seven in total. This forms a single optical surface with an aperture of 24.5 metres (80 feet) and because the mirrors are stiff, as Dr McCarthy points out, they will be able to cope well with the windy elements high up.

The telescope will also benefit from adaptive optics. Flexible secondary mirrors adjust to counteract atmospheric turbulence so, as with the other two telescopes, which also use such a system, the GMT will be able to correct atmospheric blurring. Since it has a large aperture that can hold images three times sharper than the limit for eight-metre (26-foot) apertures around today, the GMT will have resolution unlike that of any current system.

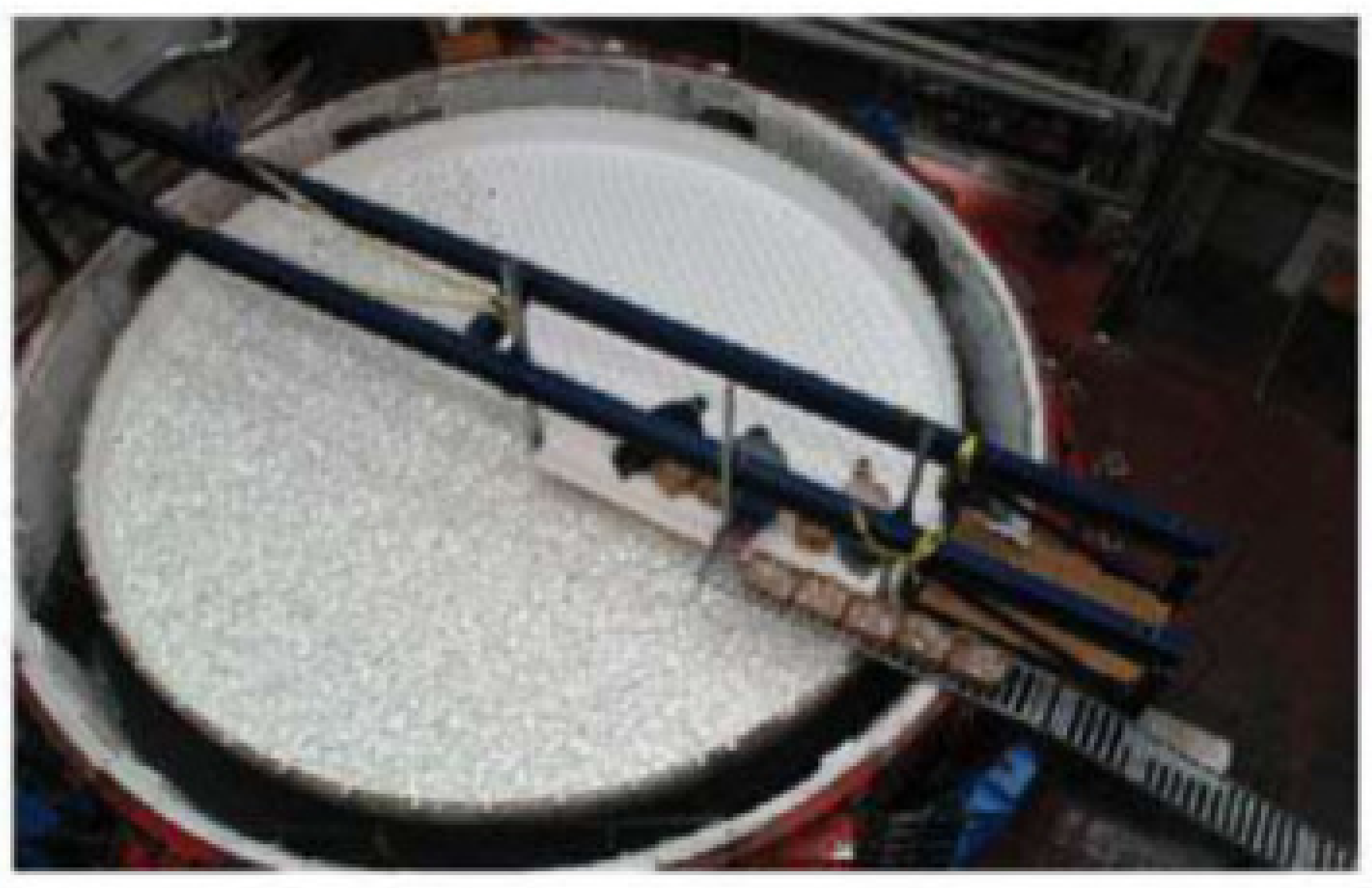
"It became clear that the new emerging field of exoplanets - the study of planets around other stars - really was crying out for a larger aperture," he says. "It really requires the improved performance from a large telescope in terms of diffraction-limited imaging, in terms of thermal background and just overall sensitivity."

By using these structured mirrors, the team can make a telescope that will be compact and optically fast. It's smaller than the E-ELT - the telescope could have had more than seven mirrors but that was the maximum the team aimed at, primarily to keep down costs - but Dr McCarthy says the difference between the two telescopes in terms of scientific performance will be slight. "I think scientists will see the same thing with the different 30-metre- [98-foot-] class telescopes," he says.

The GMT will provide them with ten times as much detail as the Hubble Space Telescope and by basing it in Chile at an altitude of over 2,500 metres (8,202 feet), it will enable them to collect fantastic images at the most cost-effective price ($1.05 billion or £610 million). The centre of the galaxy and all the major star-forming complexes go right overhead of Chile, which means the telescope can look almost anywhere in the sky outside of the Milky Way and get a fair sample of young planets.

"If you want to find locations on Earth that are well-suited to optical and infrared astronomy, you want to find a place that's dry and has clear weather," says Dr McCarthy. "But it's critical to have locations in which the air flow is very smooth, where the air is flown for hundreds and thousands of miles unimpeded before it reaches your mountain top. The Chilean Andes is perfect and there's no prospect of light pollution because it's so remote."

The GMT will enable astronomers to discover more about the universe than ever before. "We have a large list of other interesting topics involving looking back at the early universe to see the first galaxies, measuring the growth of black holes and so on and so on," Dr McCarthy says. It is set to go live in 2020.

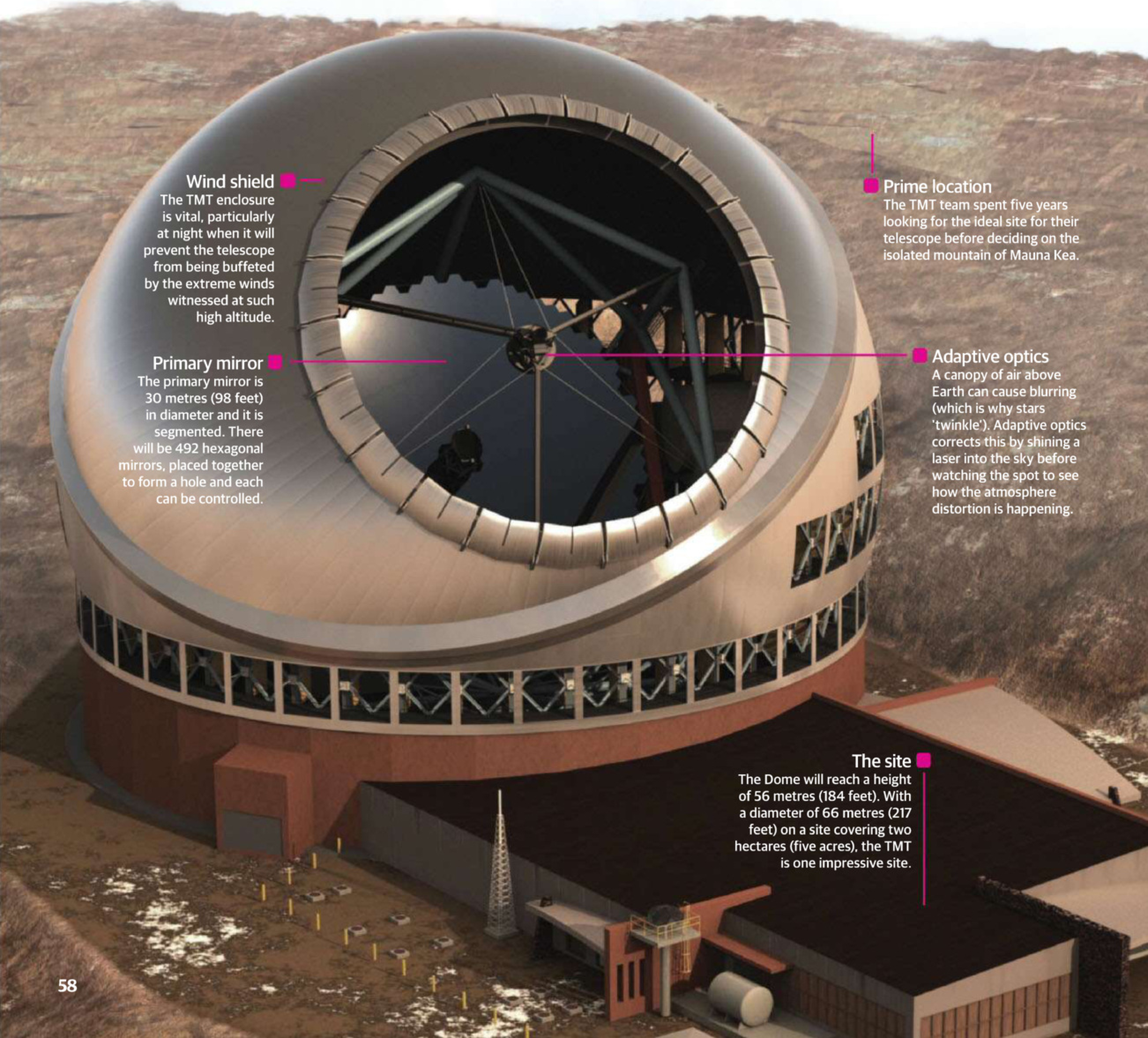


Made of glass

Constructed by the University of Arizona's Steward Observatory Mirror Lab, each of the seven mirror segments that will make up the GMT will be cast from 20 tons of glass. Our picture shows the glass being loaded into the 8.4-metre (27.6-foot) diameter furnace mould one piece at a time. When this job is complete, the lid will be placed on top and it will be heated to 1,170 degrees Celsius (2,138 degrees Fahrenheit) to melt the glass into the mould. The mirror is then polished to match a precision of 19 nanometres using a series of fine abrasives. It will then be assembled with the other mirrors to form a single 25-metre (82-foot) optical surface. So far three segments have been cast and the fourth will be ready for casting in 2015. Even though there will be seven mirrors in total, astronomers will be able to start their observations with just four in place.

China in their hands: The truly international telescope

Find out how the Thirty Meter Telescope plans to be the world's best



Wind shield
The TMT enclosure is vital, particularly at night when it will prevent the telescope from being buffeted by the extreme winds witnessed at such high altitude.

Primary mirror
The primary mirror is 30 metres (98 feet) in diameter and it is segmented. There will be 492 hexagonal mirrors, placed together to form a hole and each can be controlled.

Prime location
The TMT team spent five years looking for the ideal site for their telescope before deciding on the isolated mountain of Mauna Kea.

Adaptive optics
A canopy of air above Earth can cause blurring (which is why stars 'twinkle'). Adaptive optics corrects this by shining a laser into the sky before watching the spot to see how the atmosphere distortion is happening.

The site
The Dome will reach a height of 56 metres (184 feet). With a diameter of 66 metres (217 feet) on a site covering two hectares (five acres), the TMT is one impressive site.

INTERVIEWBIO

Dr Luc Simard
Group Leader – Instrumentation National Research Council of Canada's Herzberg Institute of Astrophysics

Larger than the GMT but smaller than the E-ELT, the Thirty Meter Telescope (TMT) represents the middle ground. As the name suggests, this telescope will have a mirror 30 metres (98 feet) in diameter at its heart and it will have a collecting area of 655 square metres (7,050 square feet). The astronomers working on it say it will become the most advanced and powerful optical telescope on Earth.

Unlike its rivals, the TMT is set to be built, not in Chile, but at the Mauna Kea Observatory in Hawaii and it is the culmination of three major projects: the California Extremely Large Telescope, the Very Large Optical Telescope in Canada and the Giant Segmented Mirror Telescope, each of which have merged into one scheme.

It is a truly international affair with the University of California, the Californian Institute of Technology, Canada, China, India and Japan joining forces. By combining such expertise, the project has been able to draw upon some very experienced astronomers.

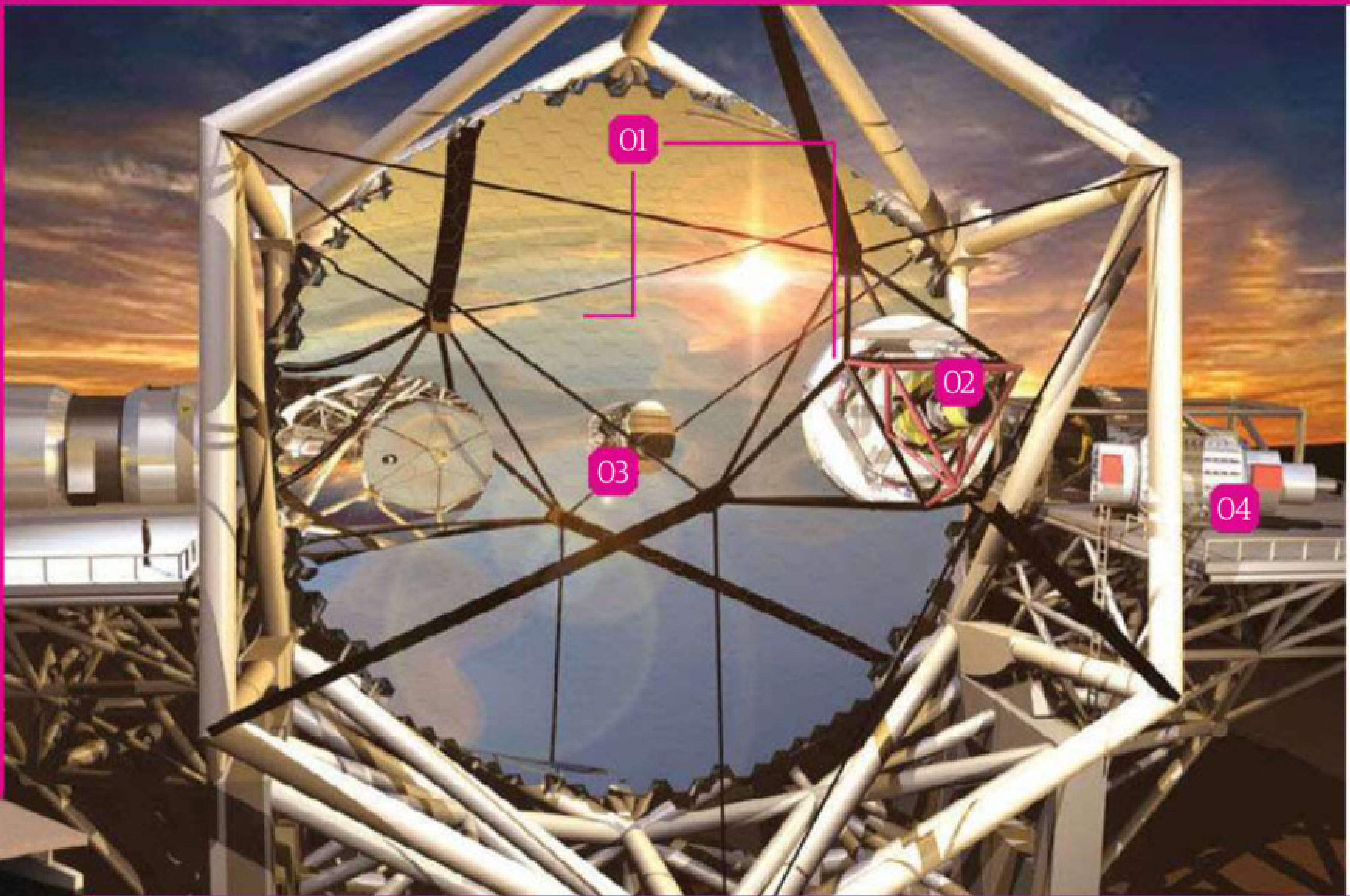
One of those is Dr Luc Simard who is developing instruments for the TMT. "The TMT continues the technology of Keck which has a ten-metre [33-foot] mirror made up of 36 segments of 1.8 metres [5.9 feet]," he says. "We are using 492 segments, each one 1.4 metres [4.6 feet] in diameter. Since we are using slightly smaller segments and many more of them, we will be able to better control the alignment and phasing when the telescope is being moved around the sky." The 492 segments behave as a single monolithic mirror that is 30 metres [98 feet] in diameter. "It's quite a powerful technology; it's very beautiful, it really scales nicely," Dr Simard says.

A secondary mirror will be three metres (9.8 feet) in diameter, which is as large as the primary mirrors of some telescopes currently in use. Working in tandem, the telescope will have nine times the collecting area of the largest telescopes around today. "That's the cool thing when you build a bigger telescope – you end up with a finer angle of resolution," he says. "So let's say you took the diameter of the full moon and you divided the diameter by two million parts, you'd be able to see about seven of those parts with TMT and that's how powerful it is." He would have loved to see the TMT even bigger than it is and says, if money was no object, that would be possible. But he adds: "There is no doubt that what we have is powerful and when you use it to look into the sky, it will show everything moving. It's the kind of thing a fine machine like TMT will be able to achieve."

By building adaptive optic systems on large platforms surrounding the telescope, astronomers will be able to shrink the size of the images so that they are close to the diffraction limit of the telescope. The diffraction-limited spatial resolution will exceed Keck by a factor of three. "Our telescope is going to be almost 200 times more powerful than the current class of eight- to ten-metre [26- to 33-foot] telescopes," he adds.

TMT is being built to be a fine all-rounder, equally at home when aimed at the Solar System to study the Moon and its planets to discover more about them as it will be looking at its outer edge. By basing it at Mauna Kea, the team believes it will have a prime spot for the telescope, allowing astronomers to observe near-ultraviolet to mid-infrared wavelengths.

The TMT will find itself 4,050 metres (13,287 feet) high – higher in altitude than the mountains being used by its rivals in Chile. "It is a really truly excellent site in terms of the number of clear nights, dryness and altitude," Dr Simard says. "You're above most of the cloud cover and above most of the water vapour in the atmosphere. It's a premier site."



TMT in focus

1 Spacing
The spacing between the segments of the primary mirror is less than three millimetres (0.1 inches). The primary and secondary mirrors are hyperboloidal and together they create a well-corrected focus.

2 Laser beams
The Laser Launch Telescope will project a constellation of six laser beams into the upper atmosphere and this will create artificial reference stars.

3 Optical axis
The optical axis of the telescope (that is, the location of the tertiary mirror) is 23 metres (75 feet) above the floor of the observatory dome, which is highly impressive indeed.

4 Grand scale
The TMT science instruments (which you can see in this picture as the cylinders on the two side platforms) are in-keeping with the overall structure: they are the size of small buildings.

What will they see?

The telescopes will boldly go where no man has gone before without even leaving Earth. But what do astronomers hope to achieve?

Astronomers believe the new wave of large telescopes will allow them to make breakthroughs that current technology simply does not allow. But the fondest hope of scientists is that they discover something completely unexpected. "And that's the most exciting thing," says Dr Patrick McCarthy.

Still, astronomers have a long list of items they would like to address and which they predict the large telescope will enable them to achieve. First on many an astronomer's list is the ability to show conclusively that there are planets out there that are conducive to supporting life.

While scientists know there are Earth-like planets that are perhaps a little larger or smaller than our own planets, if the telescopes are any indication of a new space race, then being among the first to find them will be a prime motivation. So far, none of the 1,500 exoplanets that we know of are similar enough to Earth, but it is envisaged that hundreds more will be spotted with these new telescopes, some of which may be better matched.

It is, therefore, hoped that the large telescopes will enable scientists to find water-carrying planets that are in the right temperature range. They want to find biomarkers of oxygen, methane and other chemical and molecular species that are believed to be directly related to biological processes. The telescopes will give them a very good chance of discovering life on the surface of an exoplanet, indicating whether they are covered by a rocky surface or an ocean or whether or not they contain vegetation.

The telescopes will also enable scientists to look back even further in time, uncovering the very first generation of galaxies in the universe. "We want to observe the first stars because they are very different from our own Sun," says Dr Luc Simard. "They start the story of nuclear synthesis - you can trace the products of the nuclear synthesis inside stars all the way to our own bodies."

With the ability to see the centre of the Milky Way and study a black hole 4 million times the mass of the Sun, and with hopes of being able to directly measure the acceleration of the universe's expansion, there is the possibility of our comprehension of the general laws of physics being redefined in some way.

It helps enormously that the new telescopes are able to take images at very high resolution. In doing so, scientists will be able to visually separate a planet orbiting a star from the bright glare of its parent. "Think of yourself getting onto a spaceship, flying far away from the Earth and then turning round," says Dr Joe Liske. "You'd see something extremely bright - the Sun - and something very faint - the Earth. But from a distance of a few light years, the Sun and Earth appear extremely close together. The large telescopes would change that kind of view - we'd be able to get a greater sense of their position."

With new scientific frontiers opened up, astronomers will not only uncover objects they did not know existed but also discover things they thought they knew were wrong. The discoveries won't happen straight away - it may take a few years for the scientists to learn how to make the telescope and instruments work effectively - but there should be some early advancements. We should start seeing science from 2021 and it is set to be exciting.

> "There is the possibility of our comprehension of the general laws of physics being redefined"

Gamma-ray bursts

So far, existing telescopes have been useful in telling scientists more about the burst of energetic gamma-rays. The visible light following a short-duration burst was seen for the first time in 2005. The E-ELT will see with greater clarity.

Exoplanets

There are hopes of finding an Earth-like planet reasonably close to Earth – within 30 light years or so – over the next 12 months. Once found, it will form a major target for scientists working with the E-ELT to probe them further.

Early galaxies

Astronomers want the E-ELT to work together with the James Webb Space Telescope to try and uncover the first generation of galaxies in the universe. They want to go back much further than ever before.

Planetary systems

With around 100 planetary systems well understood in terms of their orbital structures and dynamics, the team at GMTO believe between 30 and 40 of them will be clearly viewable from Chile, enabling teams to study them further.

Cold Jupiters

Hot Jupiters are the easiest extrasolar planets to uncover, which tells you that cold Jupiters are not. But because the GMT can gather light from deep into space, scientists could see Jupiter-like planets further away from their star.

Black holes

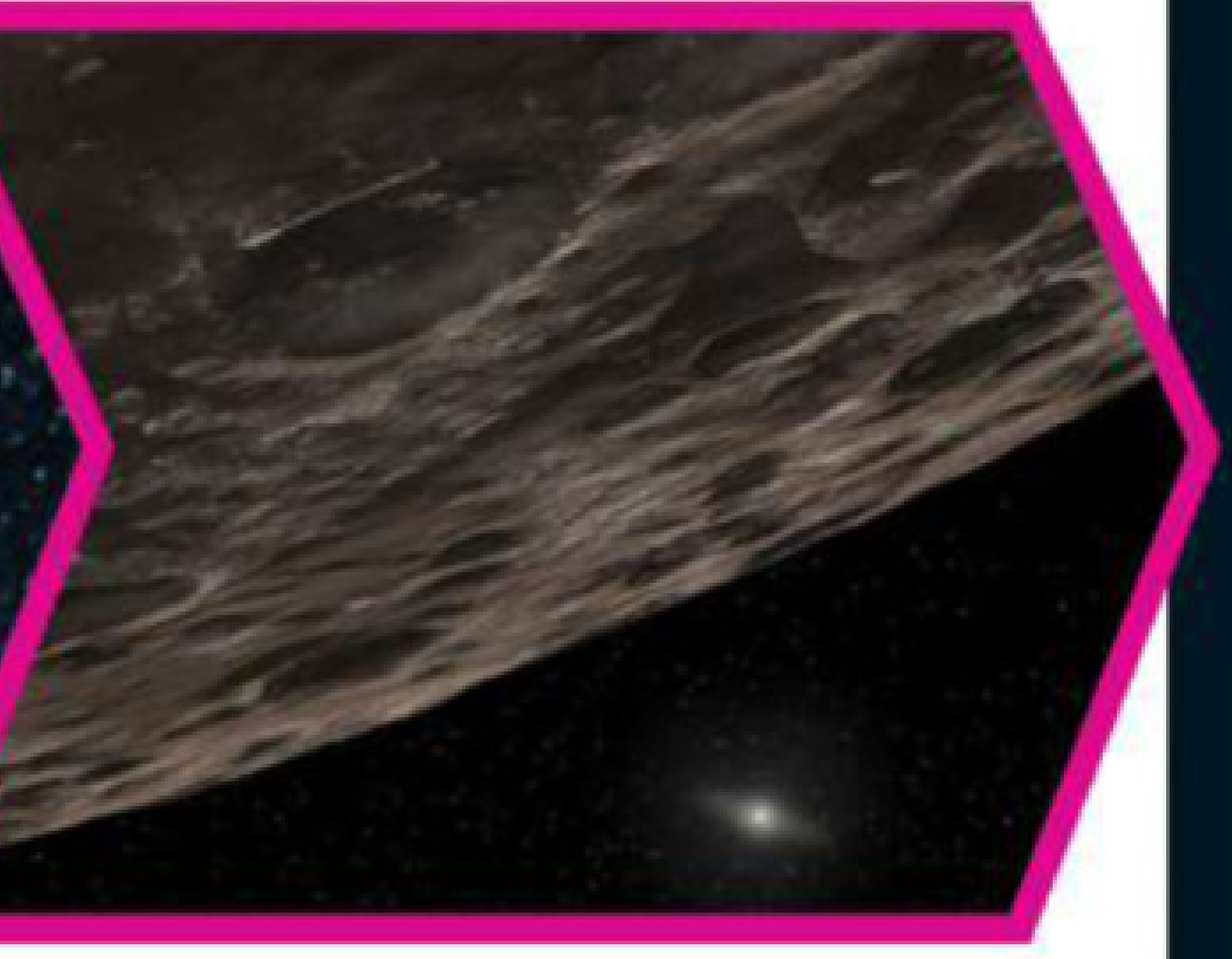
The GMTO team will be looking specifically at black holes to a distance of half way back to the Big Bang. They want to measure masses, see how they grow, ingest gas and see if they merge with other black holes.

The Moon

Sure, mankind has actually set foot on the moon. We know it's not made of cheese. But the TMT will be able to get up close and monitor its surface in real time to study any possible changes that are occurring.

Star clusters

According to Dr Luc Simard, one of the races among the three teams involved in the three telescopes could see them battling to get the first high-resolution shot of the galactic centre of a star cluster.



Kuiper belt

Beyond the planets and extending from Neptune's orbit to the sun, this huge band of objects from the formation of the Solar Systems is begging for exploration. TMT's team want to look at the chemistry.

5 things they could discover

01 More about General Relativity

Scientists will look at the orbiting stars around the supermassive black hole sitting in the centre of the Milky Way. Studying their behaviour will help them test general relativity in the vicinity of a black hole.

02 New regions

A hundred years ago, no one expected the universe to be as large as we know it is today nor did they realise it was expanding. Telescopes opened up new regions of space and the next generation will be looking to do the same.

03 Enhanced astrometry

As soon as the telescope gets going, it will provide a very powerful adaptive optic system and that means the field of astrometry – taking precise measurements of the positions of celestial bodies – will be revolutionised.

04 Dark matter's composition

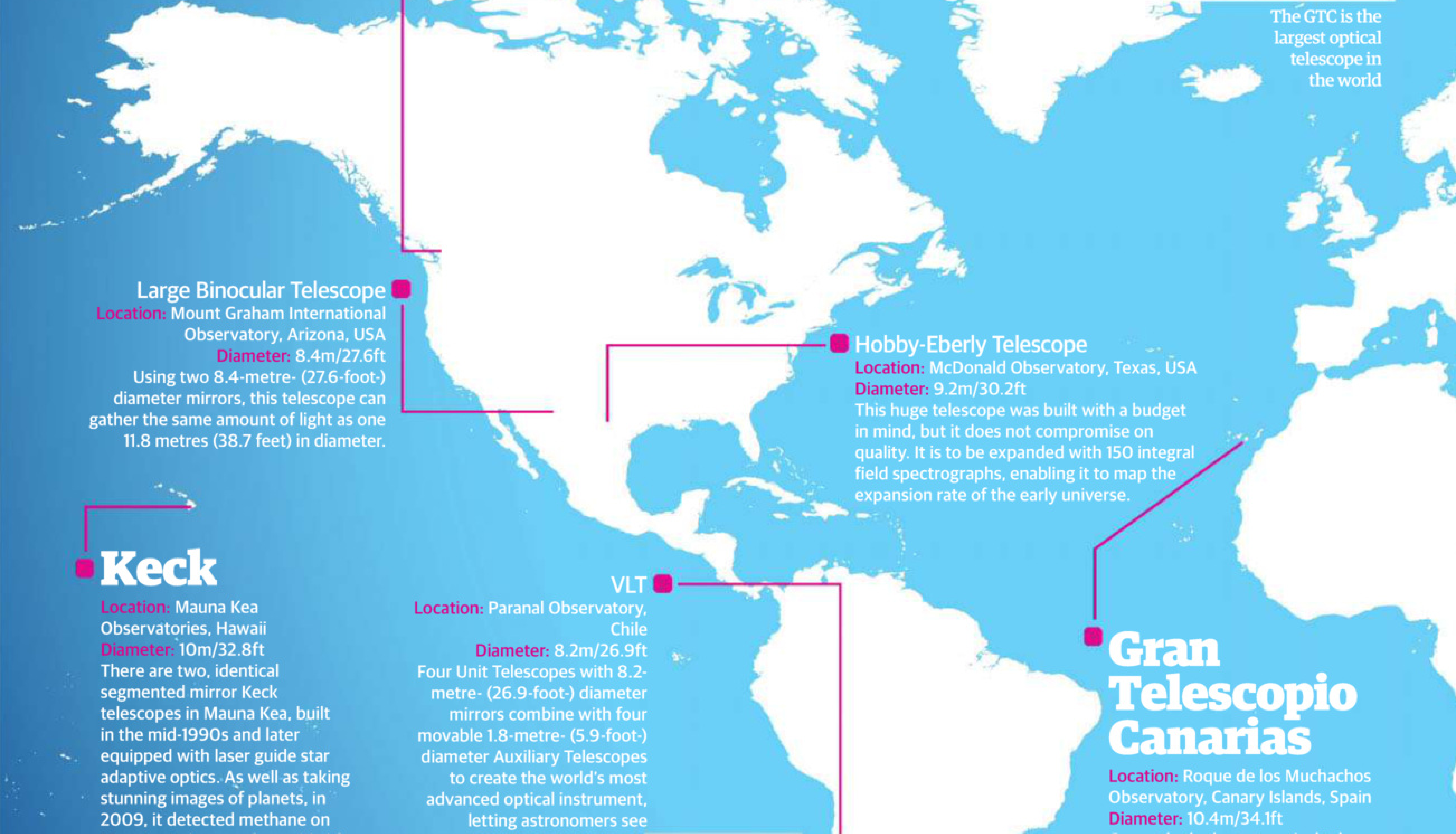
By being able to gather more light, the high-resolution telescopes will be able to study the dark matter and dark energy that comprises much of our universe.

05 Evidence of life

Are we alone? It's the big question and by studying the earliest stages of the formation of planetary systems, scientists hope detecting water or organic molecules will answer it once and for all, opening up whole new waves of intrigue and research.

10 of the world's biggest telescopes

The GTC is the largest optical telescope in the world



Large Zenith Telescope

Location: Maple Ridge, British Columbia, Canada

Diameter: 6m/20ft

Able only to look at the zenith – an imaginary point directly above the spot being studied – the LZT can measure spectral energy, distributions and redshifts of more than 100,000 galaxies and quasars.

Large Binocular Telescope

Location: Mount Graham International Observatory, Arizona, USA

Diameter: 8.4m/27.6ft

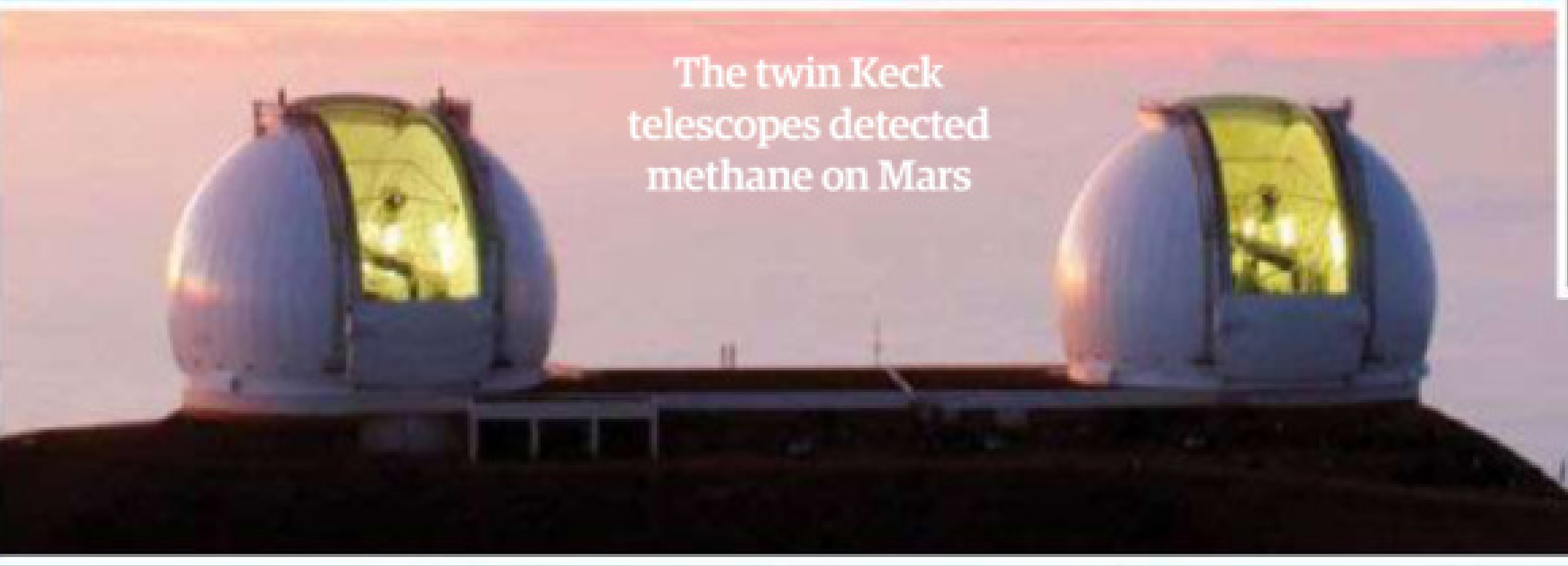
Using two 8.4-metre- (27.6-foot-) diameter mirrors, this telescope can gather the same amount of light as one 11.8 metres (38.7 feet) in diameter.

Keck

Location: Mauna Kea Observatories, Hawaii

Diameter: 10m/32.8ft

There are two, identical segmented mirror Keck telescopes in Mauna Kea, built in the mid-1990s and later equipped with laser guide star adaptive optics. As well as taking stunning images of planets, in 2009, it detected methane on Mars, an indicator of possible life.



The twin Keck telescopes detected methane on Mars

VLT

Location: Paranal Observatory, Chile

Diameter: 8.2m/26.9ft

Four Unit Telescopes with 8.2-metre- (26.9-foot-) diameter mirrors combine with four movable 1.8-metre- (5.9-foot-) diameter Auxiliary Telescopes to create the world's most advanced optical instrument, letting astronomers see impeccable detail

Hobby-Eberly Telescope

Location: McDonald Observatory, Texas, USA

Diameter: 9.2m/30.2ft

This huge telescope was built with a budget in mind, but it does not compromise on quality. It is to be expanded with 150 integral field spectrographs, enabling it to map the expansion rate of the early universe.

Gran Telescopio Canarias

Location: Roque de los Muchachos Observatory, Canary Islands, Spain

Diameter: 10.4m/34.1ft

Currently the largest optical telescope in the world, the GTC made its first observation in 2007. Sitting atop a volcanic peak at an altitude of 2,267m (7,438ft), it has picked up galaxies as far as 25 million light years away.

Magellan

Location: Las Campanas Observatory, Chile

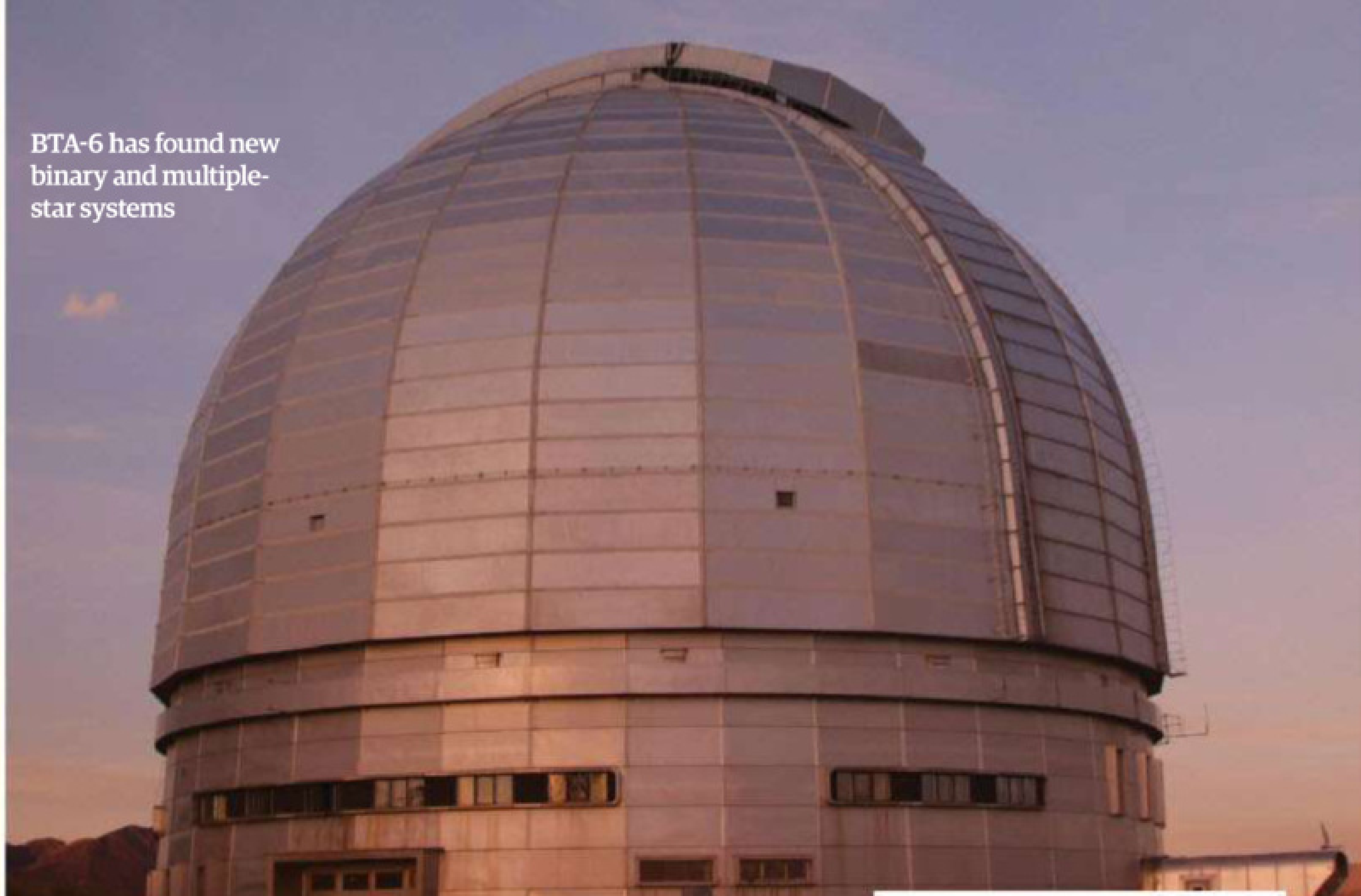
Diameter: 6.5m/21.3ft

These two telescopes are located 60 metres (197 feet) apart. The mirrors are made of borosilicate glass with a lightweight honeycomb structure. They are said to be the best natural imaging telescopes in the world.

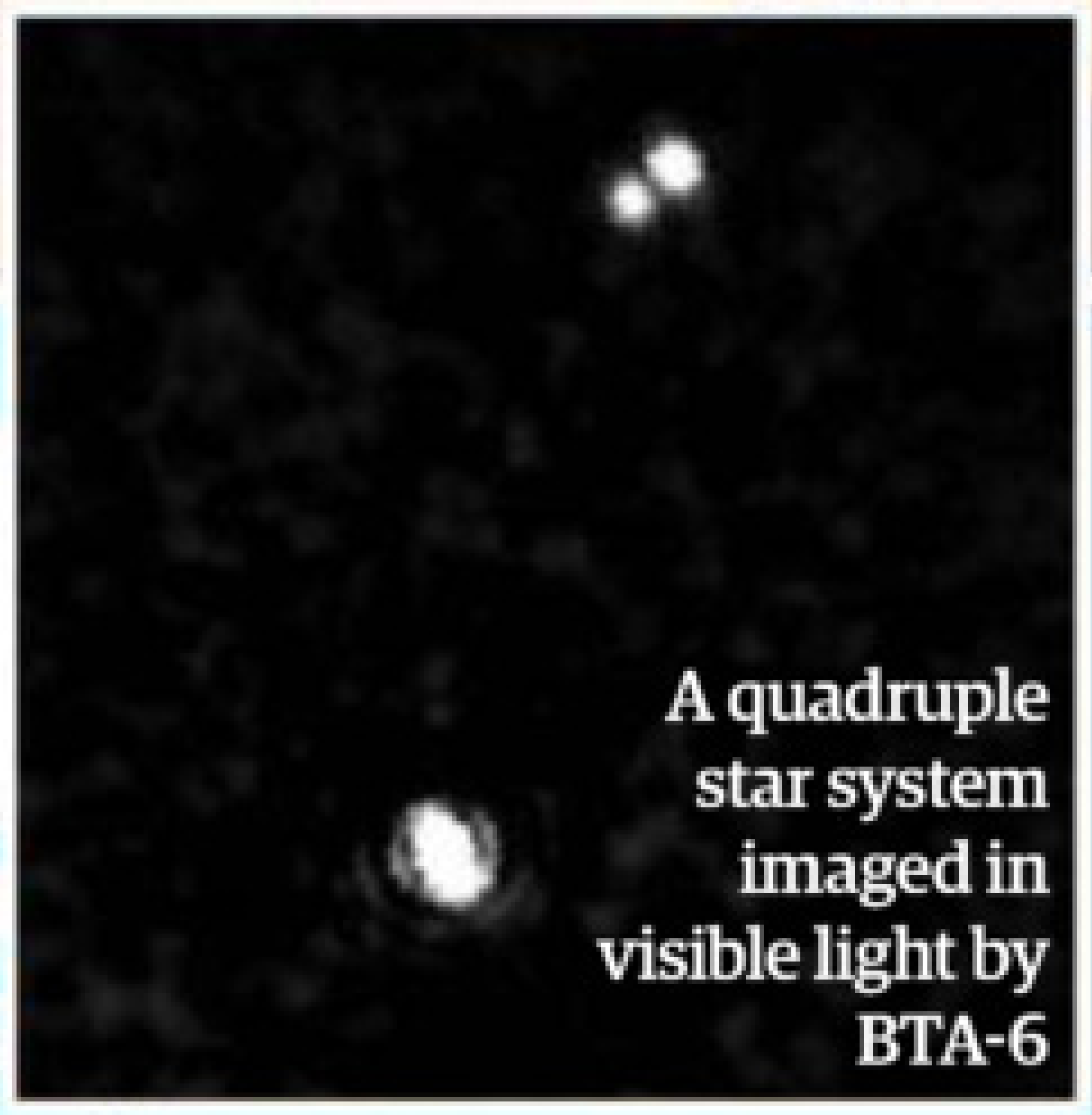
BTA-6

Location: Special Astrophysical Observatory, Russia
Diameter: 6m/19.7ft

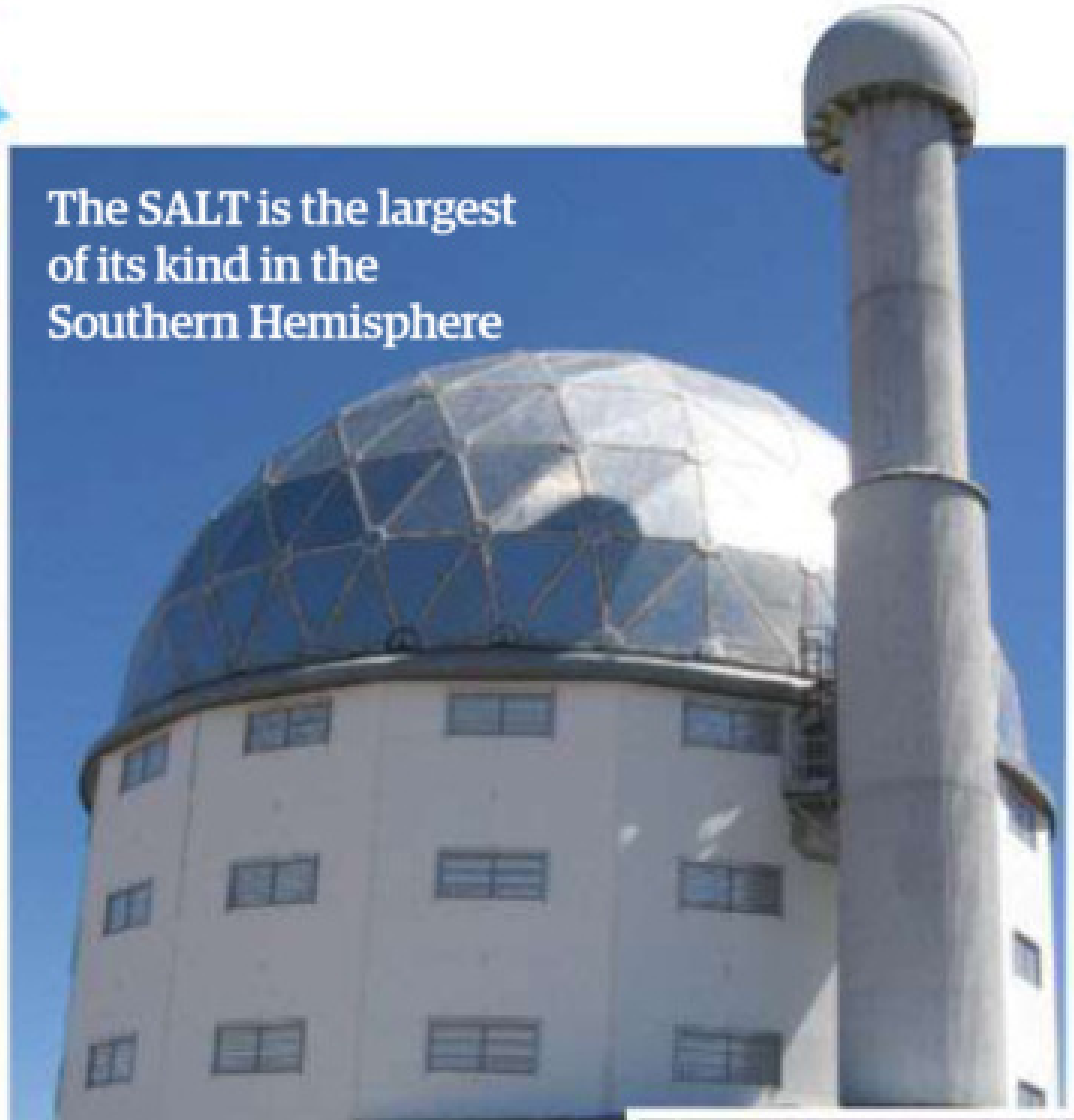
The BTA-6, in the Caucasus Mountains of Russia, was dubbed a white elephant soon after it began to operate due to issues with the mirror. Since rectified, it recently discovered new binary and multiple star systems with magnetic compounds.



BTA-6 has found new binary and multiple-star systems



A quadruple star system imaged in visible light by BTA-6



The SALT is the largest of its kind in the Southern Hemisphere

Southern African Large Telescope

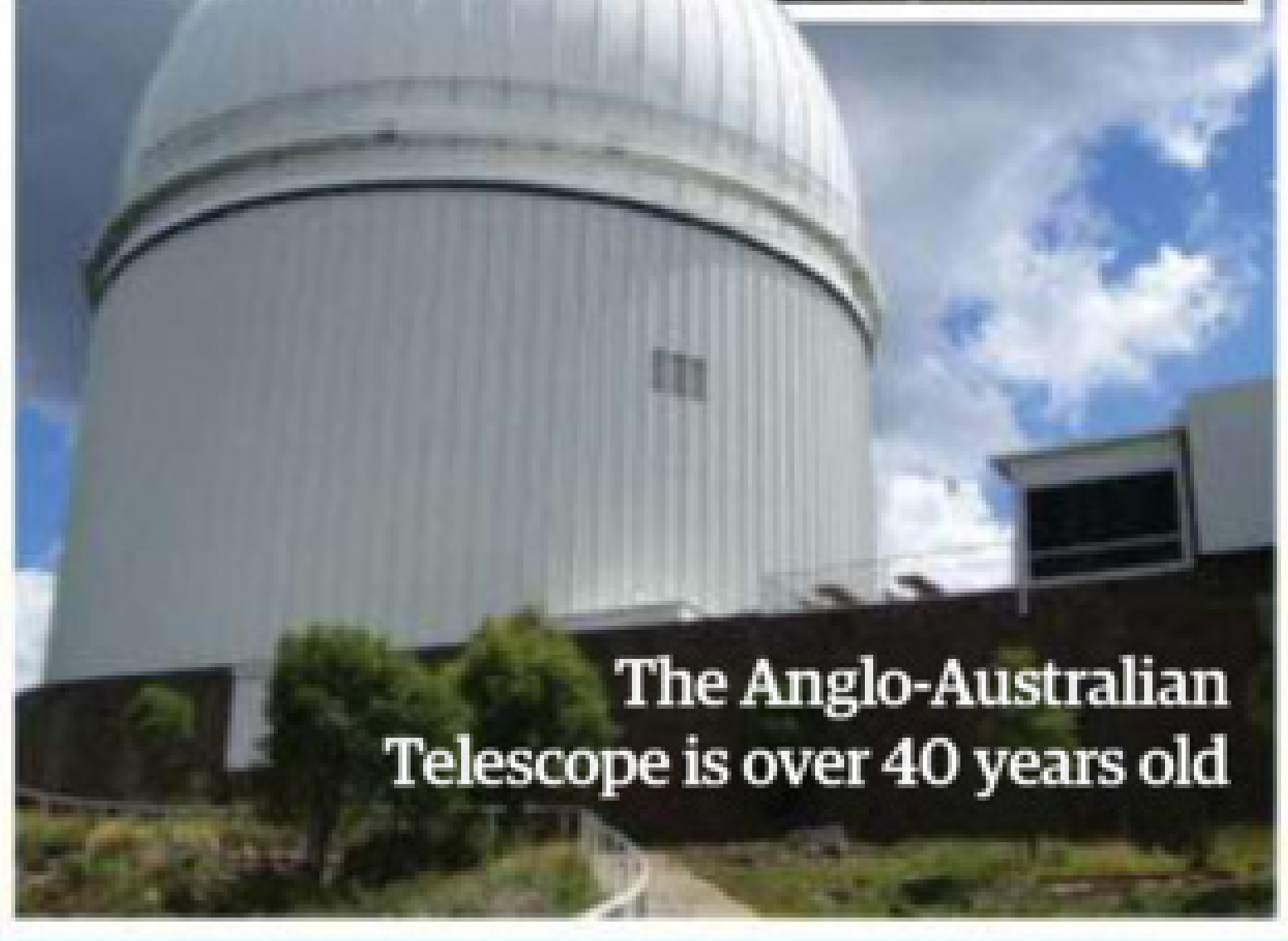
Location: South African Astronomical Observatory, Northern Cape, South Africa
Diameter: 9.8m/32.2ft

As the largest ground-based optical instrument in the southern hemisphere, its hexagonal primary mirror is over 9.8 metres (32.2 feet) in diameter. It's aim is to study the absorption and emission of light and other radiation by matter of astronomical objects.

Anglo-Australian Telescope

Location: Siding Spring Observatory, New South Wales, Australia
Diameter: 3.89m/12.8ft

Celebrating 40 years on Earth, many scientific publications have been based on the discoveries of this telescope. In 2013, scientists in Australia found the last giant outburst of energy from the supermassive black hole in the centre of our galaxy took place two million years ago.



The Anglo-Australian Telescope is over 40 years old

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5 Amazing facts

Total solar eclipses

This rare interaction in the sky is a once-in-a-lifetime sight for many

© YAY Media AS/Alamy

They won't be around forever

The Moon has been gradually moving away from the Earth since its formation, so that a few hundred million years ago it was too close to precisely cover the disk of the Sun. In the far future, the Sun will have expanded in its older age and the Moon moved so far away that it will no longer cover it entirely. This means that solar eclipses will only be around for a while, and the last one will occur around six hundred million years from now.

Eclipses are dangerous

While viewing an eclipse without protection can damage your eyesight as much as staring directly at the Sun, the dip in brightness can make looking up at totality a temptation. Retinas can be damaged very quickly this way, even within a fraction of a second if the eclipse is viewed through binoculars, a telescope or the viewfinder of a camera.

They helped confirm Einstein's theory of relativity

A total solar eclipse in 1919 helped confirm the theory of general relativity, four years after Einstein had published it. The total eclipse showed a gravitation lens in action – with the Sun between the Earth and the stars while the Moon occulted its bright disc, the Sun's gravity could be seen to magnify the light from the stars.

They're getting shorter

A number of factors determine the duration of a total solar eclipse, crucially how close the Moon is to its pedigree, when it's closest to Earth. The maximum duration of totality is currently seven minutes and 32 seconds, though that figure is steadily decreasing over millennia. However, by following the path of totality in a fast aircraft, observation of a total eclipse as it happens can be extended to over an hour.

Total eclipses are rare

While one total solar eclipse occurs somewhere on Earth at least every 18 months or so, they only happen in the exact same place approximately once every 400 years. Today's transport has made travelling to the path of totality a possibility for most, but in the past you'd have been lucky to see a total solar eclipse during your lifetime.

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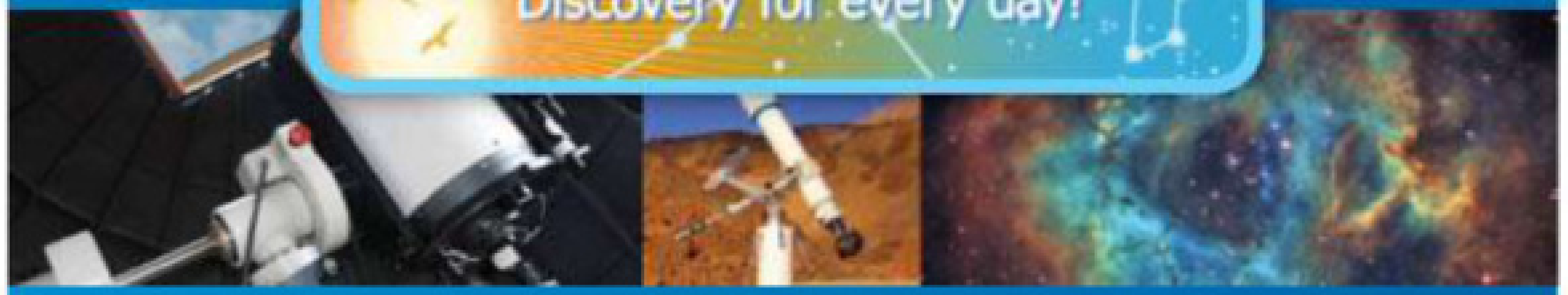

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OUTER SPACE QUARANTINE

Why do we need to stop germs spreading through space and how does the Planetary Protection programme prevent this?

Written by Luis Villazon

We may not have discovered any alien civilisations yet, but mission planners are still bound by the equivalent of *Star Trek*'s Prime Directive. Article IX of the United Nations' Outer Space Treaty requires space-faring nations to make sure that space exploration doesn't accidentally contaminate our world, or those that we visit. At NASA, responsibility for that falls to Dr Catharine Conley, planetary protection officer for the Science Mission Directorate. "We know, from experience on Earth, that moving organisms into novel environments can have unexpected effects - invasive species and infectious diseases have demonstrated this," explains Dr Conley. "The objective of planetary protection is to prevent similar unfortunate things from happening, both when we go to other planetary objects and when we bring material back to Earth."

Planetary protection is about reducing risk, not eliminating it altogether. It isn't realistic or necessary to insist that spacecraft can't be launched if there is even a single germ clinging to the surface somewhere. "Very few spacecraft are actually sterilised, if by sterilised one means treated so there are no living organisms present," says Dr Conley. "Spacecraft going to places that can't host Earth life, which is almost everywhere in the Solar System, are assembled in clean rooms, but have no more constraints than that." For Mars and certain other moons of Jupiter and Saturn though, we need to be much more careful.

Planetary protection isn't just a question of avoiding the spread of diseases. In order to look for signs of life on other planets, spacecraft use very sensitive instruments that look for organic molecules in the soil and record the uptake of radioactively labelled nutrients. If one of these experiments ever records a positive result, scientists need to be absolutely sure that it wasn't caused by bacteria hitchhiking from Earth. In the 1970s, when the Viking probes were sent to Mars, the best way to definitively kill all microbes was to bake the entire spacecraft in a huge oven. That's much harder to do nowadays, because modern electronics are almost as easily destroyed by heat as the bugs themselves are. However, research is ongoing to find ways of sterilising spacecraft with chemicals such as

CONTAINMENT

Why we need quarantine:

To protect Earth
An invasive species can wreak havoc when introduced into a new environment.

To protect future missions
An Earth organism could cause a false alert on a mission looking for any signs of life.

ZONE

Apollo 11 Moon plague

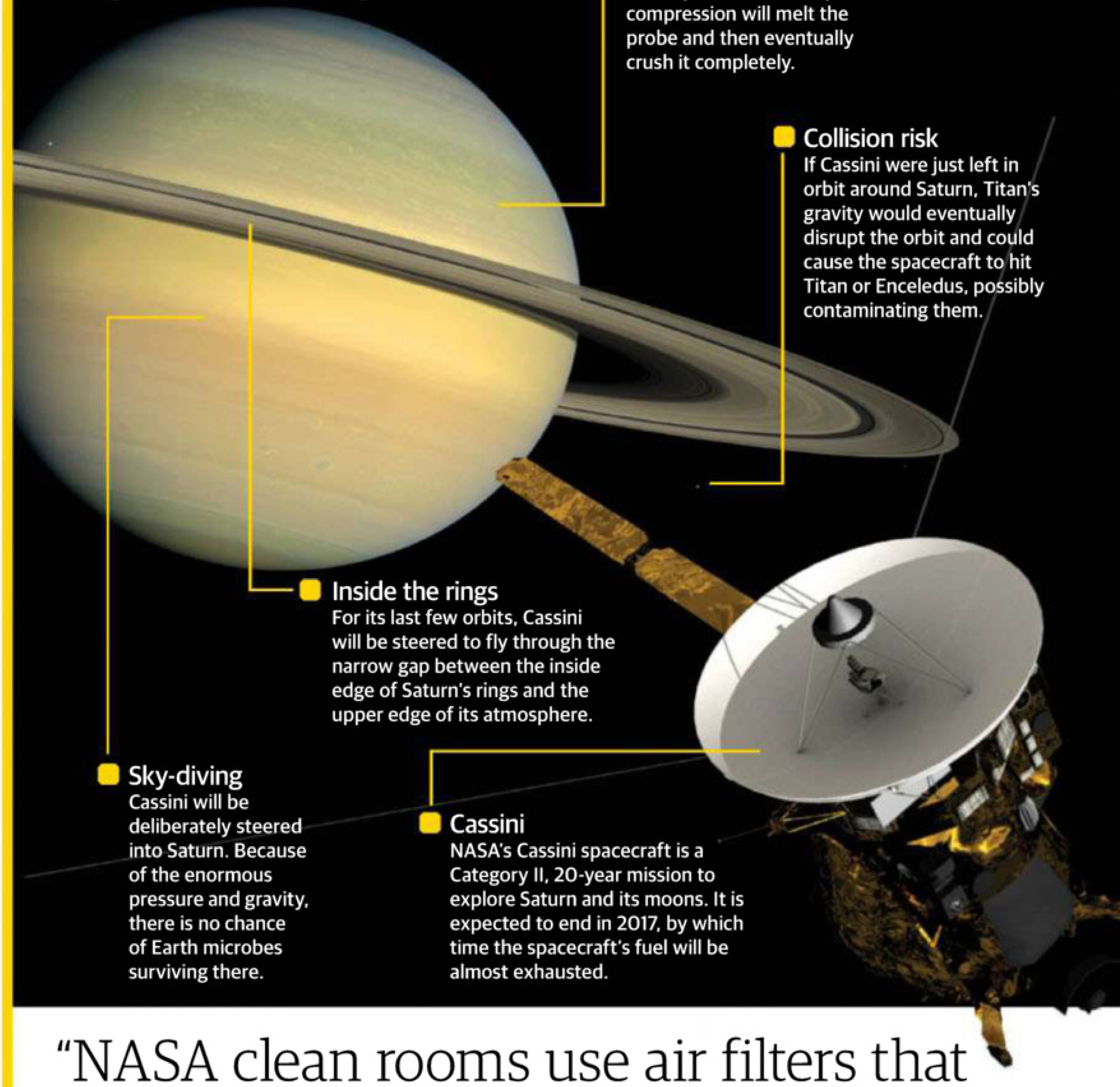
We once thought the Moon could harbour deadly germs

In 1969 scientists had yet to definitively establish that the Moon was lifeless. NASA was concerned that the returning Apollo astronauts could bring space germs back with them, so it designed elaborate quarantine procedures. When the Apollo 11 command module splashed down, a rescue diver dropped from a helicopter with a pair of life rafts. One of these was used as a floating decontamination station. The diver put on a special biological isolation garment, or BIG suit, then cracked open the hatch on the command module and quickly threw in three more BIG suits before shutting the hatch again. While Neil Armstrong, Buzz Aldrin and Michael Collins put their suits on, the outside of the hatch was sprayed with bleach to disinfect it. The hatch was opened a second time and the astronauts clambered into the decontamination raft where they were each sprayed with more bleach.

After that they were winched aboard the helicopter and taken to the USS Hornet, where they went immediately to one of the four mobile quarantine facilities (MQFs) that NASA had converted from Airstream caravans at a cost of $250,000. Each MQF had its own food supply and air-filtration system. The three astronauts, plus a doctor and a technician, stayed inside the MQF as it returned to Pearl Harbor aboard the USS Hornet, before being loaded onto a truck, then a C-141 cargo plane and flown to Houston. All five men had another two weeks of quarantine ahead of them in the Lunar Receiving Laboratory. This quarantine system was used for Apollo 12 and 14 as well, but the concerns about a 'Moon plague' had abated by 1971 and the crews of the last three Apollo missions were spared the discomfort of the MQF trailers for the last leg of their journey home.

The three Apollo 11 astronauts in their green BIG suits step from the helicopter straight into the waiting mobile quarantine facility

Keep the Solar System tidy



High pressure
Saturn's atmosphere has no oxygen, so Cassini won't burn up, but the atmospheric compression will melt the probe and then eventually crush it completely.

Collision risk
If Cassini were just left in orbit around Saturn, Titan's gravity would eventually disrupt the orbit and could cause the spacecraft to hit Titan or Enceledus, possibly contaminating them.

Inside the rings
For its last few orbits, Cassini will be steered to fly through the narrow gap between the inside edge of Saturn's rings and the upper edge of its atmosphere.

Sky-diving
Cassini will be deliberately steered into Saturn. Because of the enormous pressure and gravity, there is no chance of Earth microbes surviving there.

Cassini
NASA's Cassini spacecraft is a Category II, 20-year mission to explore Saturn and its moons. It is expected to end in 2017, by which time the spacecraft's fuel will be almost exhausted.

> "NASA clean rooms use air filters that trap 99.97 per cent of particles"

hydrogen peroxide, which won't severely damage the spacecraft itself.

In the meantime, NASA clean rooms use air filters that trap 99.97 per cent of particles larger than 300 nanometers, which is about the size of the smallest bacteria. Spacecraft and all the surfaces of the clean room itself are regularly cleaned with iso-propyl alcohol. Unlike ammonia-based disinfectants, this doesn't leave an organic residue behind when it dries. After the spacecraft is built, it may be stored and transported in a pressurised container so that air tends to leak outwards, rather than inwards, and a pressurised tent may also be erected at the launch site when the spacecraft is integrated with the rocket.

When you consider that the spacecraft will then be exposed to the vacuum, ultraviolet and other forms of radiation in space for several years before it even reaches its target planet, this can start to look like overkill. Even so, some bacteria and fungal spores are known to be able to survive in space and even if they don't, the organic molecules present in their dead bodies could still affect the readings of some of the most sensitive instruments. Even with all their stringent procedures, NASA technicians recently discovered a new species of bacteria called Tersicoccus phoenicis. This species has only been found into two places on Earth and both of them are spacecraft assembly clean rooms. This isn't an indictment of sloppy standards at NASA - in fact, it's quite the reverse. The clean rooms are so sterile that only this tiny, hardy little bug remains and the literally microscopic scrutiny that every surface is subjected to, means that every strain and species of bacteria is detected and catalogued.

Planetary protection doesn't end once the spacecraft has been launched. A strategy known as trajectory biasing is used to prevent orbiters from accidentally crashing on other planets. The spacecraft

Keep it clean

Modern spacecraft are assembled in conditions that rival an operating theatre

1. Clean room

All spacecraft are assembled in clean room facilities to prevent dust and metal filings from damaging instruments. But planetary protection also involves air-conditioning systems that blow a smooth stream of highly filtered air across the facility.

2. Protective clothing

Everyone in the room must wear a head-to-foot bunny suit and powder-free gloves, to minimise the chance of skin flakes or bacterial spores falling on the spacecraft. Every scientist and technician wears a fresh set every day.

3. Wipe down

Components for some spacecraft may also be carefully cleaned with alcohol wipes during assembly to further remove any organic grime and kill bacteria that may be lurking in crevices.

4. Sterilisation

The Viking landers sent to Mars were placed inside bioshields – like giant casserole dishes – and baked inside an oven at 112 degrees Celsius (234 Fahrenheit) for 30 hours. Planetary protection accounted for ten per cent of the mission cost.

5. Microbial assays

To check that the spacecraft and the assembly facility are clean enough, technicians regularly take surface swabs and culture them to see how many viable spores remain. The target is no more than 22 spores per square metre (two spores per square foot).

Every inch of a clean room is checked for the tiniest bacteria

> "Spacecraft that bring samples back to Earth are subject to the very highest category of protection"

is initially aimed deliberately off-target, by as much as a few hundred thousand kilometres, so that if there is a navigational error or communication is lost, it will simply disappear harmlessly into deep space. As the spacecraft gets closer and more-accurate telemetry is available, the spacecraft makes a series of correction burns to progressively eliminate this safety margin.

Spacecraft that bring samples back to Earth are subject to the highest category of protection. This may seem strange at first - Earth receives a constant bombardment of meteorites that originated on other planets, so why should the samples that we bring back deliberately be handled so carefully? "Meteorites from Mars that land on Earth have generally been travelling through space for thousands to millions of years before they land here," says Dr Conley. "The hard radiation and other conditions in space, for that long a period of time, are expected to destroy any organisms that might have been present when the material was ejected from Mars. This is very different from an active sample-return mission from Mars, which will take only a few years to transport material from Mars to Earth.

"Samples returned from most places in the Solar System are treated like any other valuable scientific samples: the Hayabusa, Genesis, and Stardust missions are examples. Samples from Mars and other places that could host indigenous life that might survive on Earth... will be contained at a similar level... to protect the Earth and also to protect them from contamination by Earth compounds [in case there is] indigenous life in those samples." ■

New Horizons

Category: II

Target: Pluto, Charon

Status: Ongoing

New Horizons will briefly fly past Pluto next year before leaving the Solar System. It will be about 10,000 kilometres (6,214 miles) from Pluto at its closest point.

Juno

Category: II

Target: Jupiter

Status: Ongoing

At the end of Juno's mission it will burn up in Jupiter's atmosphere to avoid contaminating the moons, which are more-likely prospects for life.

Mars Climate Orbiter

Category: III

Target: Mars

Status: Failed

This spacecraft disintegrated in the atmosphere of Mars due to a trajectory error, but its Category III status ensured that the surface remained safe from contamination.

Mars Science Laboratory

Category: IV

Target: Mars

Status: Ongoing

The Curiosity rover doesn't carry experiments to look for the presence of life directly, so it receives the slightly lower IVa sub-category.

Mars Phoenix Lander

Category: IVc

Target: Mars

Status: Completed

Phoenix had the highest sub-category because it landed near Mars's north pole, where there was known to be an amount of water ice present.

Rosetta

Category: II/III

Target: Comet C-G, Asteroid Lutetia

Status: Ongoing

Landing on the comet will only be Category II. The biggest worry for Rosetta was that it might contaminate Mars during its flyby.

OSIRIS-REx

Category: V (unrestricted)

Target: Asteroid Bennu

Status: Under construction

This mission will bring back at least 60 grams (2.1 ounces) of pristine rock from the asteroid. The precautions are to protect the sample, rather than Earth.

Categories of risk

Every space mission is assessed for its potential to contaminate another mission

Category I – minimal risk

Missions to the Sun, Mercury and Jupiter's volcanic moon Io, are the least vulnerable to contamination. This is simply because no Earth microbes could survive there. No special precautions are needed before launch or during the mission. Category I is almost never used because even a gravity assist around Venus is enough to bump the mission to Category II.

Category II – low risk

This is where the planet or moon might be able to tell us something about the chemistry of the early Solar System, but the mission itself has almost no chance of contaminating that body. These missions are assembled in clean rooms.

Category III – medium risk

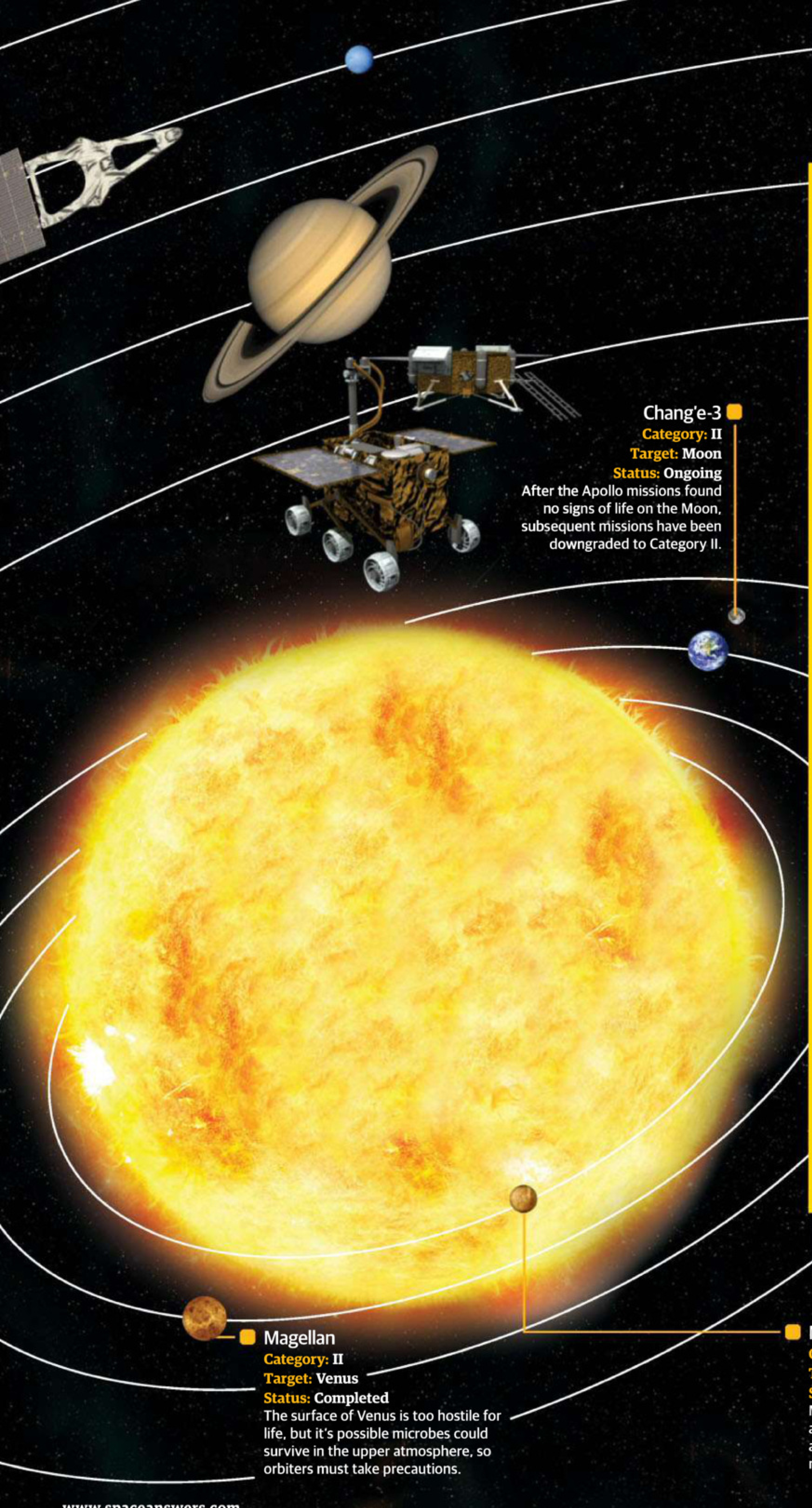
Flyby and orbiter missions to most other bodies come under Category III. Orbital trajectories must be carefully calculated so the spacecraft does not crash onto the surface. The spacecraft is assembled and integrated with the launch rocket in clean-room conditions.

Category IV – high risk

Mars, Europa and Enceladus all have evidence to suggest there may be either liquid water or underground environments that could harbour life. Landers and rovers to these bodies are cleaned during assembly to reduce the number of bacterial spores. In some cases the spacecraft is also fully sterilised.

Category V – critical risk

Any sample-return mission is automatically Category V. If the planet or moon isn't expected to harbour life of its own, the mission is Category V Unrestricted. If there is any doubt, it is Category V Restricted. Planners must be able to guarantee that the spacecraft won't crash or break as it returns to Earth.



Chang'e-3
Category: II
Target: Moon
Status: Ongoing
After the Apollo missions found no signs of life on the Moon, subsequent missions have been downgraded to Category II.

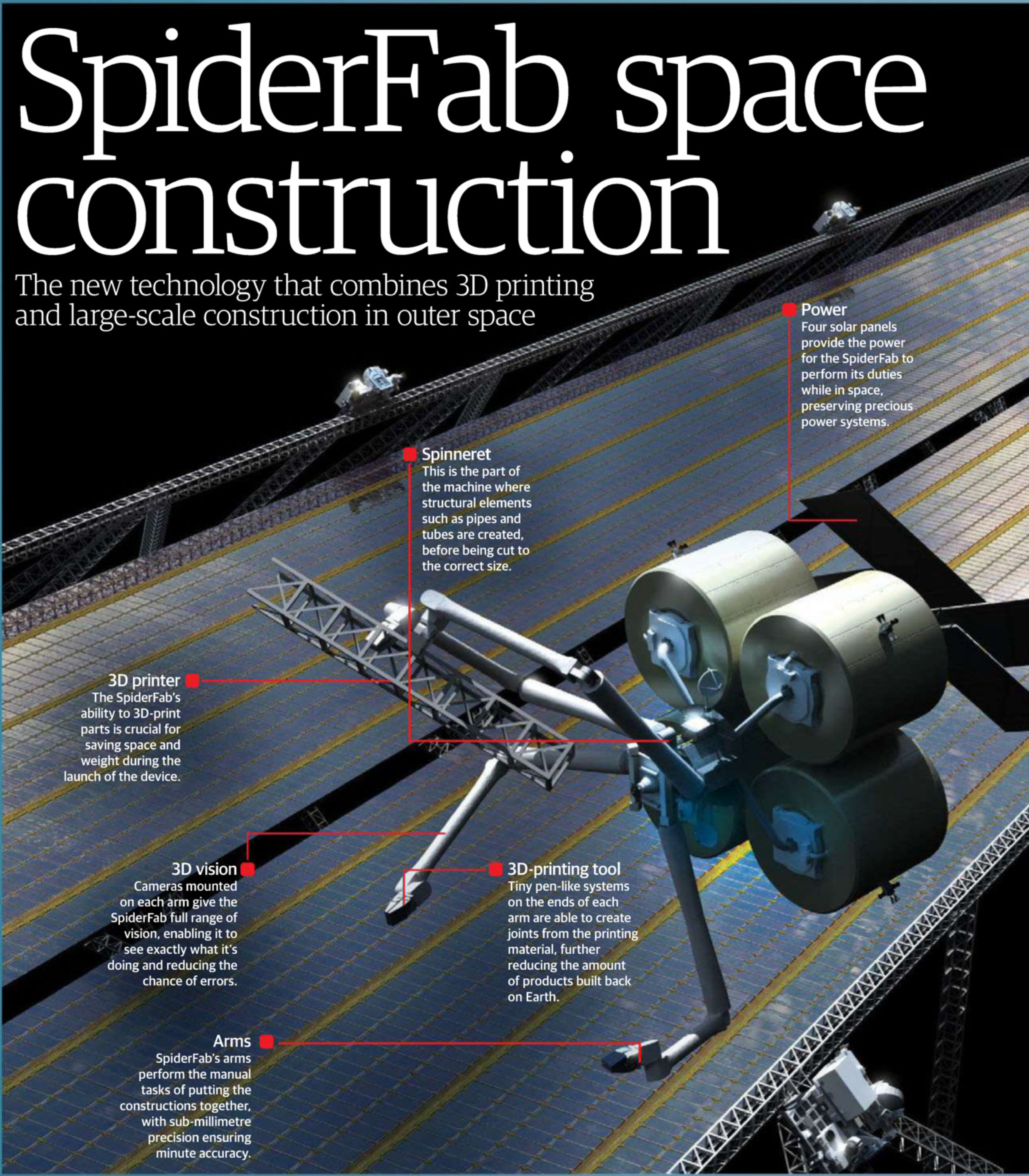
Magellan
Category: II
Target: Venus
Status: Completed
The surface of Venus is too hostile for life, but it's possible microbes could survive in the upper atmosphere, so orbiters must take precautions.

MESSENGER
Category: II
Target: Mercury
Status: Ongoing
MESSENGER received a gravity-assist from Venus and so is classed as Category II, even though it does not pose any risk to Mercury itself.

© NASA

SpiderFab space construction

The new technology that combines 3D printing and large-scale construction in outer space



Power
Four solar panels provide the power for the SpiderFab to perform its duties while in space, preserving precious power systems.

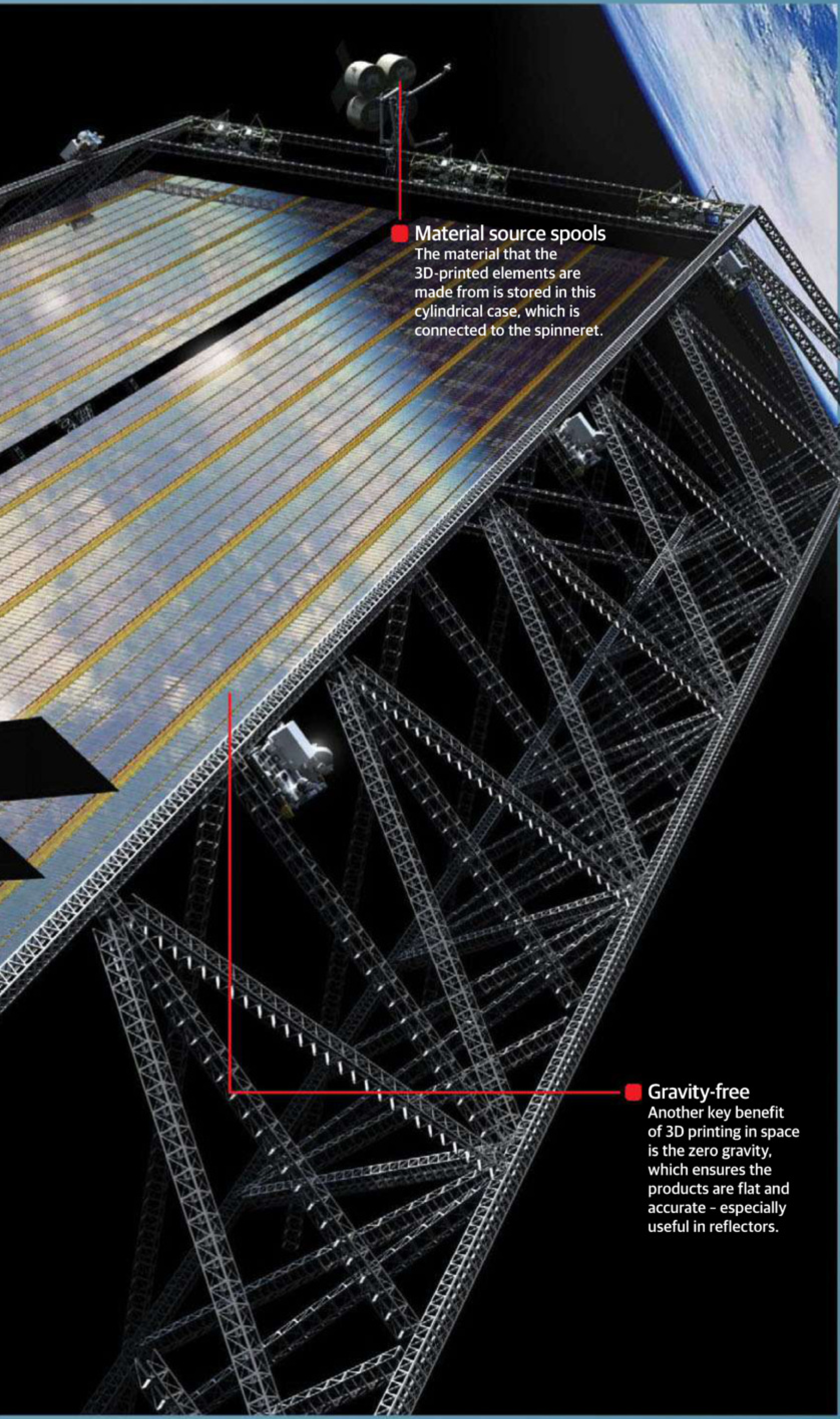
Spinneret
This is the part of the machine where structural elements such as pipes and tubes are created, before being cut to the correct size.

3D printer
The SpiderFab's ability to 3D-print parts is crucial for saving space and weight during the launch of the device.

3D vision
Cameras mounted on each arm give the SpiderFab full range of vision, enabling it to see exactly what it's doing and reducing the chance of errors.

3D-printing tool
Tiny pen-like systems on the ends of each arm are able to create joints from the printing material, further reducing the amount of products built back on Earth.

Arms
SpiderFab's arms perform the manual tasks of putting the constructions together, with sub-millimetre precision ensuring minute accuracy.



Material source spools
The material that the 3D-printed elements are made from is stored in this cylindrical case, which is connected to the spinneret.

Gravity-free
Another key benefit of 3D printing in space is the zero gravity, which ensures the products are flat and accurate – especially useful in reflectors.

If you think putting together an IKEA wardrobe is tough, you should see one of the latest technologies to get the green light from NASA's Institute of Advanced Concepts (NIAC).

SpiderFab is a creation from Tethers Unlimited that will build structures in space, slashing the cost and difficulty of launching mission devices. At the moment structures like the Starshade, for the New Worlds Observer mission, have to be put together on Earth before being launched into space. This requires a large and powerful rocket, increasing both the cost and difficulty of the mission.

The idea behind the SpiderFab is to have all the individual components stored in the payload and, once the smaller, more-efficient rocket has delivered them safely into space, it will get to work constructing the device. The Starshade is essentially a large screen placed in front of a space telescope that enables it to photograph the exoplanets of far-away stars, so the benefits for constructing this using the SpiderFab are plain to see.

By sending the Starshade up in pieces to be put together in space, efficient packing would enable the construction to be twice the size, with exactly the same mass and an incredible 1/30th of the volume – halving the mission cost.

The 3D-printing element is a key aspect of the SpiderFab's appeal. It can construct elements such as carbon-fibre tubes, seemingly from nowhere, once again saving hugely on the space used and the cost of sending pre-built tubes into space.

It can also 3D-print joints, meaning that it only needs to be sent up with the bare-minimum of pre-built objects and the material to 3D-print the rest. It's accurate to sub-millimetre levels so scientists should have few concerns about accuracy.

The SpiderFab is aptly named, as its appearance is much like a spider, with a number of limbs that it uses to assemble the structure, along with a 3D vision system to enable it to detect what it's doing.

Another amazing thing about the device is its sheer range of abilities. Not only does it have the handyman skills to construct a device in outer space, but SpiderFab can create many useful space products such as parabolic reflectors, optical mirrors, solar arrays and phased array antennas. Far from being a one-trick pony, the SpiderFab could be the solution to sending products into space far more easily and cheaply.

With this new-found flexibility, scientists could learn more about the universe, sending up more missions due to reduced cost. They could also push the boundaries of what we previously thought was possible, once the SpiderFab has made bigger, better and more-accurate astral constructions a real possibility. We could gaze further, in greater detail, and perhaps even travel vaster distances, all thanks to one small, multi-limbed, 3D-printing robot. ●

> "SpiderFab could be the solution to sending products into space"

© Adrian Mann

The artificial star

When the ESO needs a star, it just creates its own

Sometimes there just isn't a bright star you can calibrate your sensitive telescopes by, in the right place at the right time. And unfortunately, even at the high altitude of the European Southern Observatory's Paranal site in Chile, with its still air and impeccably clear skies, the atmosphere of Earth creates turbulence that distorts any observations made of objects in space. Without any correction, the Very Large Telescope array's four 1.8-metre- (six-foot-) aperture instruments are totally unable to resolve images any better than an everyday 20-centimetre (eight-inch) telescope.

To counter this, a clearly visible star near the target is used to calibrate instruments - unfortunately only one in 100 are bright enough. So in the absence of a suitable star, the VLT makes its own. Yepun is one of the four units that make up the VLT and it's equipped with the Laser Guide Star (LGS) - a powerful instrument that beams a yellow laser 90 kilometres (56 miles) into the atmosphere, where it hits a layer of sodium atoms thought to be left over from meteorites. By energising these atoms a reference point is created, an artificial star that can be used to prevent the VLT's images from blurring.

Once the VLT has calibrated its telescopes with the Laser Guide Star, it can detect objects four billion times weaker than the faintest object the human eye can see

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In proud association with the National Space Centre *www.spacecentre.co.uk*

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National Space Academy Education Officer

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Zoe Baily

National Space Centre

■ Zoe holds a Master's degree in interdisciplinary science and loves the topic of space as it brings together many different scientific disciplines.

Josh Barker

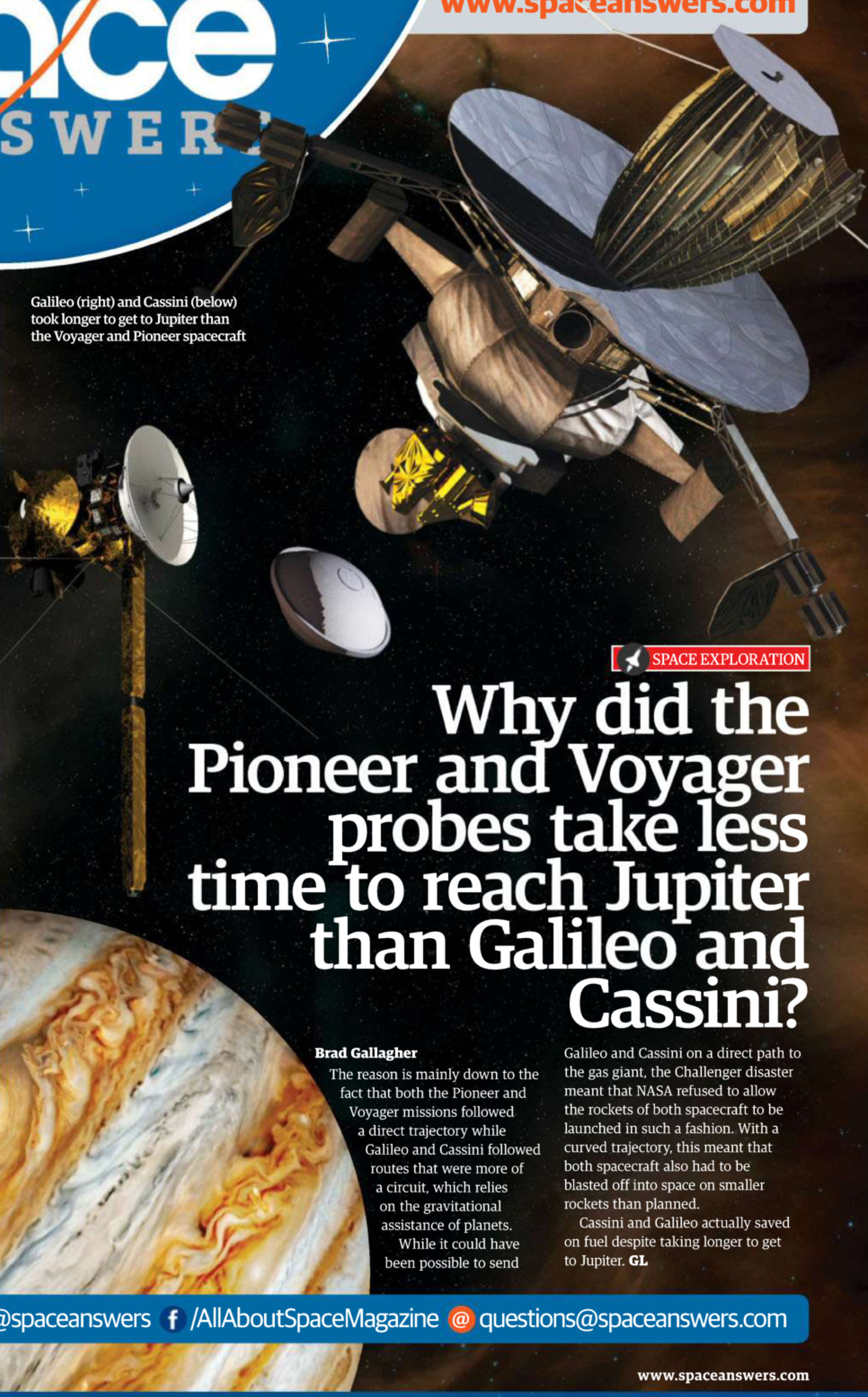
Education Team Presenter

■ Having achieved a Master's in physics and astrophysics, Josh continues to pursue his interest in space at the National Space Centre.

Gemma Lavender

Senior staff writer

■ Gemma has been elected as a fellow of the Royal Astronomical Society and is a keen stargazer and telescope enthusiast on **All About Space** magazine.



Galileo (right) and Cassini (below) took longer to get to Jupiter than the Voyager and Pioneer spacecraft

SPACE EXPLORATION

Why did the Pioneer and Voyager probes take less time to reach Jupiter than Galileo and Cassini?

Brad Gallagher

The reason is mainly down to the fact that both the Pioneer and Voyager missions followed a direct trajectory while Galileo and Cassini followed routes that were more of a circuit, which relies on the gravitational assistance of planets.

While it could have been possible to send Galileo and Cassini on a direct path to the gas giant, the Challenger disaster meant that NASA refused to allow the rockets of both spacecraft to be launched in such a fashion. With a curved trajectory, this meant that both spacecraft also had to be blasted off into space on smaller rockets than planned.

Cassini and Galileo actually saved on fuel despite taking longer to get to Jupiter. **GL**

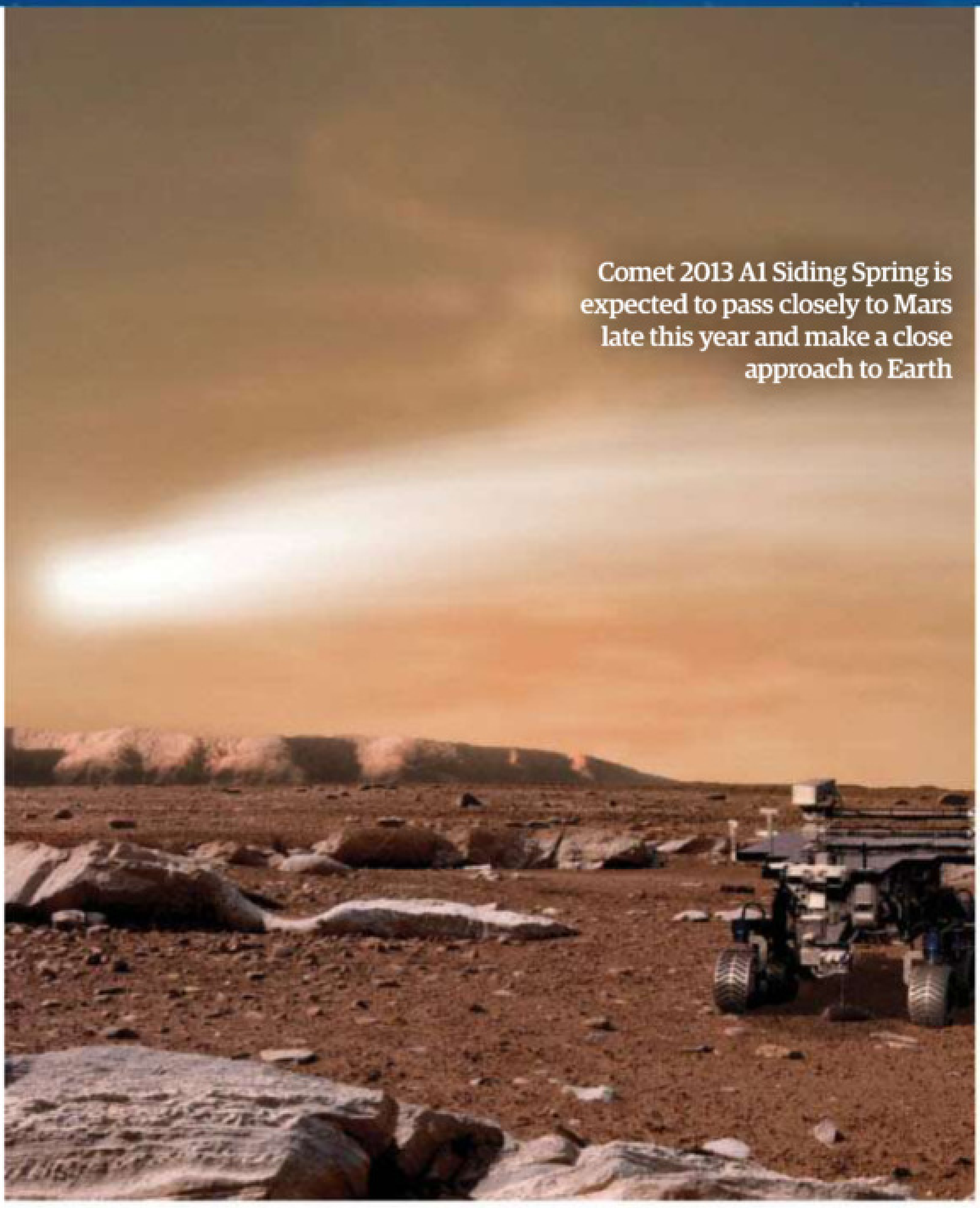
Make contact: @spaceanswers /AllAboutSpaceMagazine questions@spaceanswers.com

SOLAR SYSTEM

Which comet will pass by Earth next?

Joseph Cunningham

C/2012 K1 (PANSTARRS) may still be visible with binoculars as it passes this month. Over 70 are expected to make their closest approach to the Sun during this year, passing by us on their way to perihelion. Sadly, 2014 does not offer a great deal in terms of returning, periodic comets that will be bright and observable with the naked eye. Long period comets that have travelled in towards from as far as the Oort cloud at the edge of our Solar System are a lot more difficult to predict. One of these comets, C/2013 A1 Siding Spring, is expected to pass very close by Mars late this year. In 2013, over 60 new comets were identified, so there is always the possibility that there are many to pass by us that we just haven't spotted yet. **ZB**


Comet 2013 A1 Siding Spring is expected to pass closely to Mars late this year and make a close approach to Earth

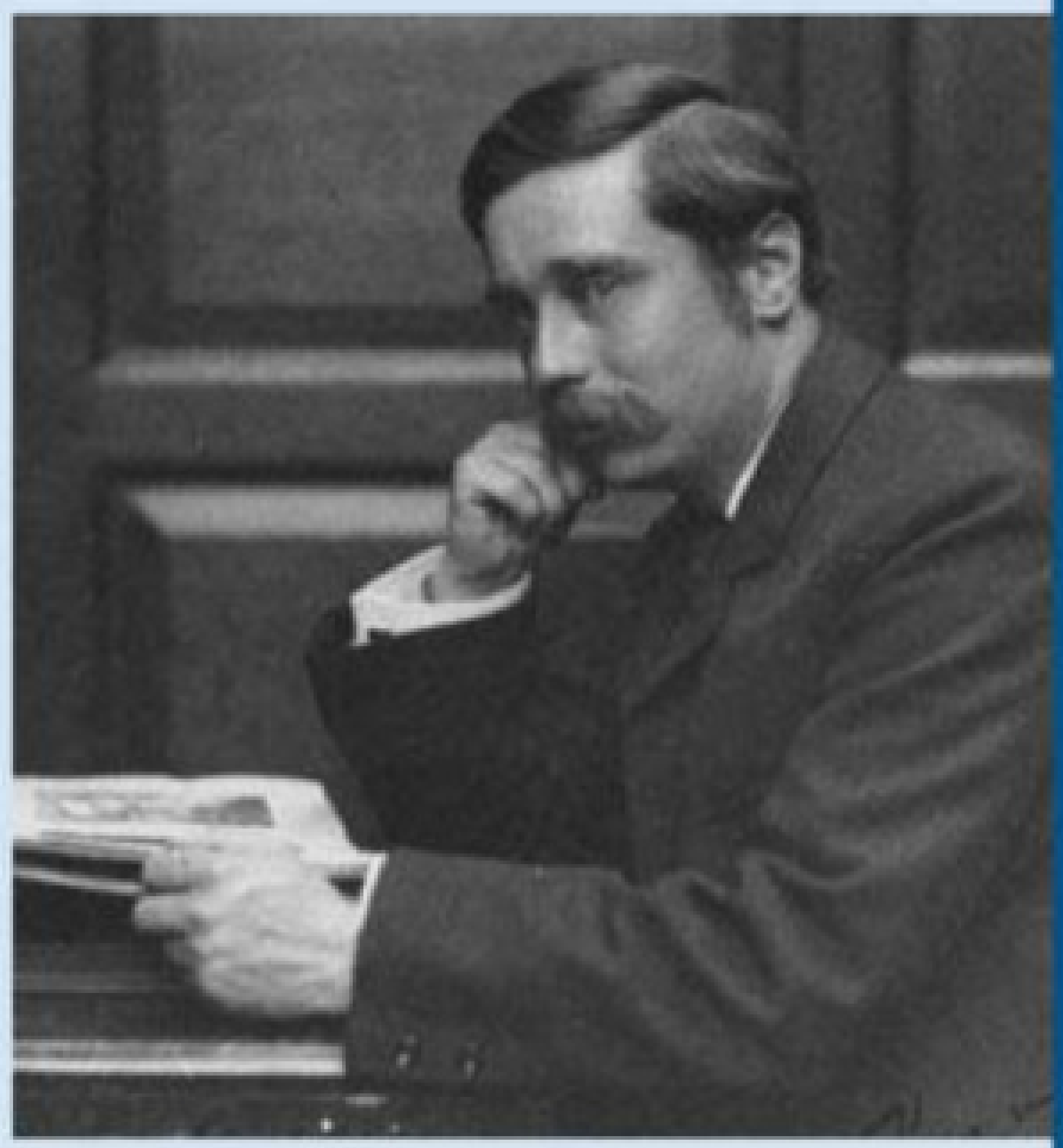
ASTRONOMY

Is there a difference between astronomy and astrophysics?

Nigel Bennett

Many argue that there isn't really a difference between the two and the terms are used interchangeably since a degree of physics is required to understand findings. However, technically speaking, astronomy is the study of anything beyond the Earth's atmosphere and involves the measurements of positions and characteristics of heavenly bodies. Astrophysics, on the other hand, concerns itself more with the application of physics to understand astronomy. An astrophysicist works to understand the physical processes associated with celestial objects and the space between them including the physics of stars, planets, black holes and their formation, evolution and ultimate future. Yet an astronomer would be more interested in observing the night sky, taking careful note of positions of the objects within it. **GL**

An astronomer observes the night sky, while an astrophysicist works to understand the physical processes associated with the objects in the universe


The idea of exploring space has been presented in the works of authors such as H.G. Wells who penned The War of the Worlds

SPACE EXPLORATION

Who initially decided that we should venture into space?

Andy Blunt

The desire to explore space isn't really something that was kick-started by one person. Since before the beginning of recorded history, people have observed space and discussed what it might be, where the objects in it came from and talked about exploring beyond the surface of the Earth. The idea of exploring space has often been presented in works of fiction most famously by authors such as H.G. Wells and Jules Verne. The actual exploration of space didn't really begin until the 1940s when rocketry technology developed at pace and weaponry started to be repurposed for exploration. **JB**

Gamma-ray bursts release incredible amounts of energy

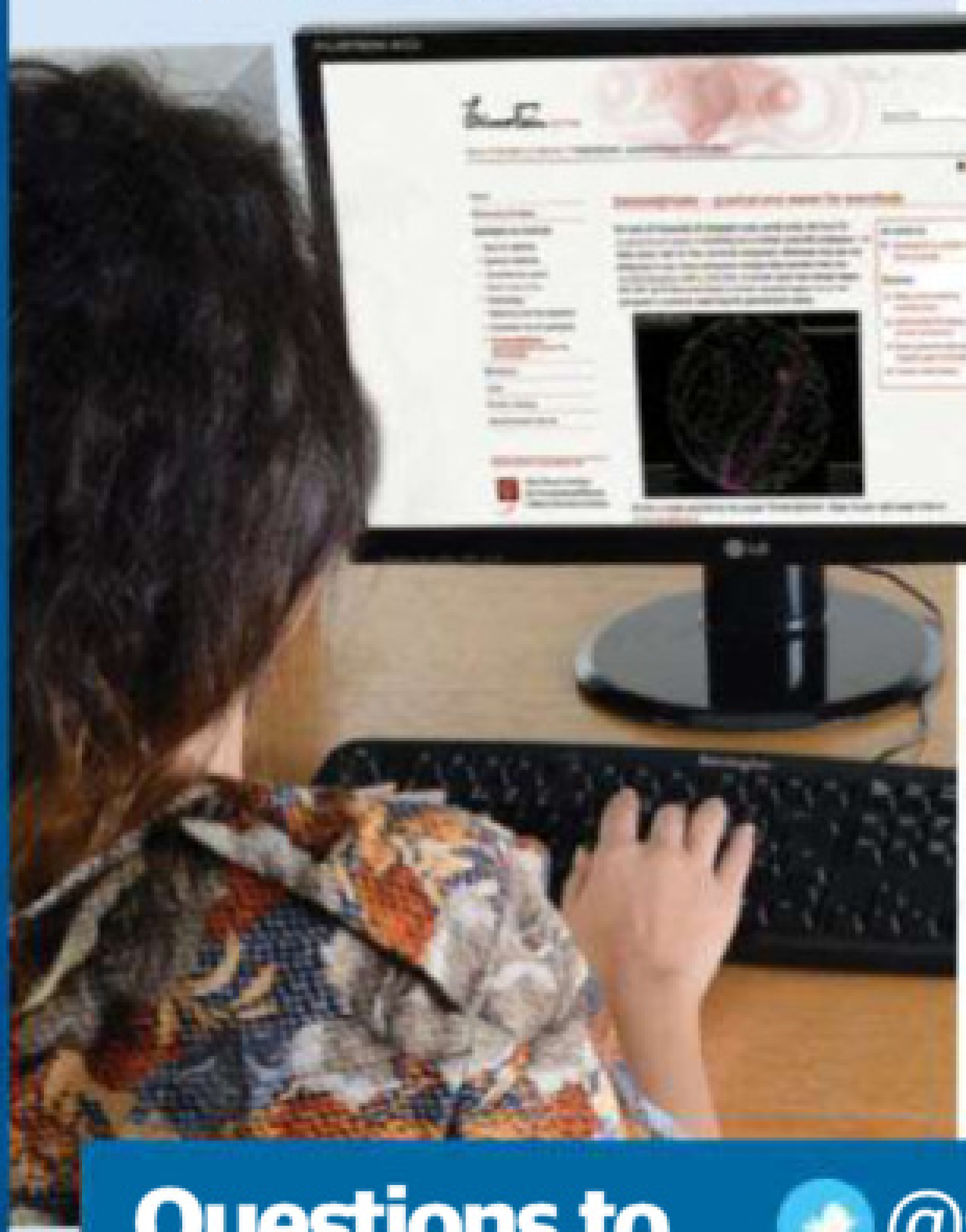
ASTRONOMY

Can I get involved in gamma-ray astronomy?

Luis Priest

The problem with gamma rays is that they are absorbed by Earth's atmosphere. This is lucky for us in the sense of protecting us from dangerous high-energy radiation, but a problem for astronomers who want to look for gamma-ray sources emitted from high-energy objects such as supernova and gamma-ray pulsars.

As a result, gamma-ray telescopes are launched into space, beyond the atmospheric shield and so hands-on gamma-ray astronomy is difficult to do outside of a research department. However, if you would like to participate in a citizen science project, like the volunteers who helped find new young gamma-ray pulsars, you can take part in the Einstein@Home project and give some of your computing power over to real astronomy research. **SA**



You can take part in citizen science project, Einstein@Home, to help find young gamma-ray pulsars

Elliptical galaxy IC 1101, at the centre of the Abell 2029 galaxy cluster, is the largest we know of

DEEP SPACE

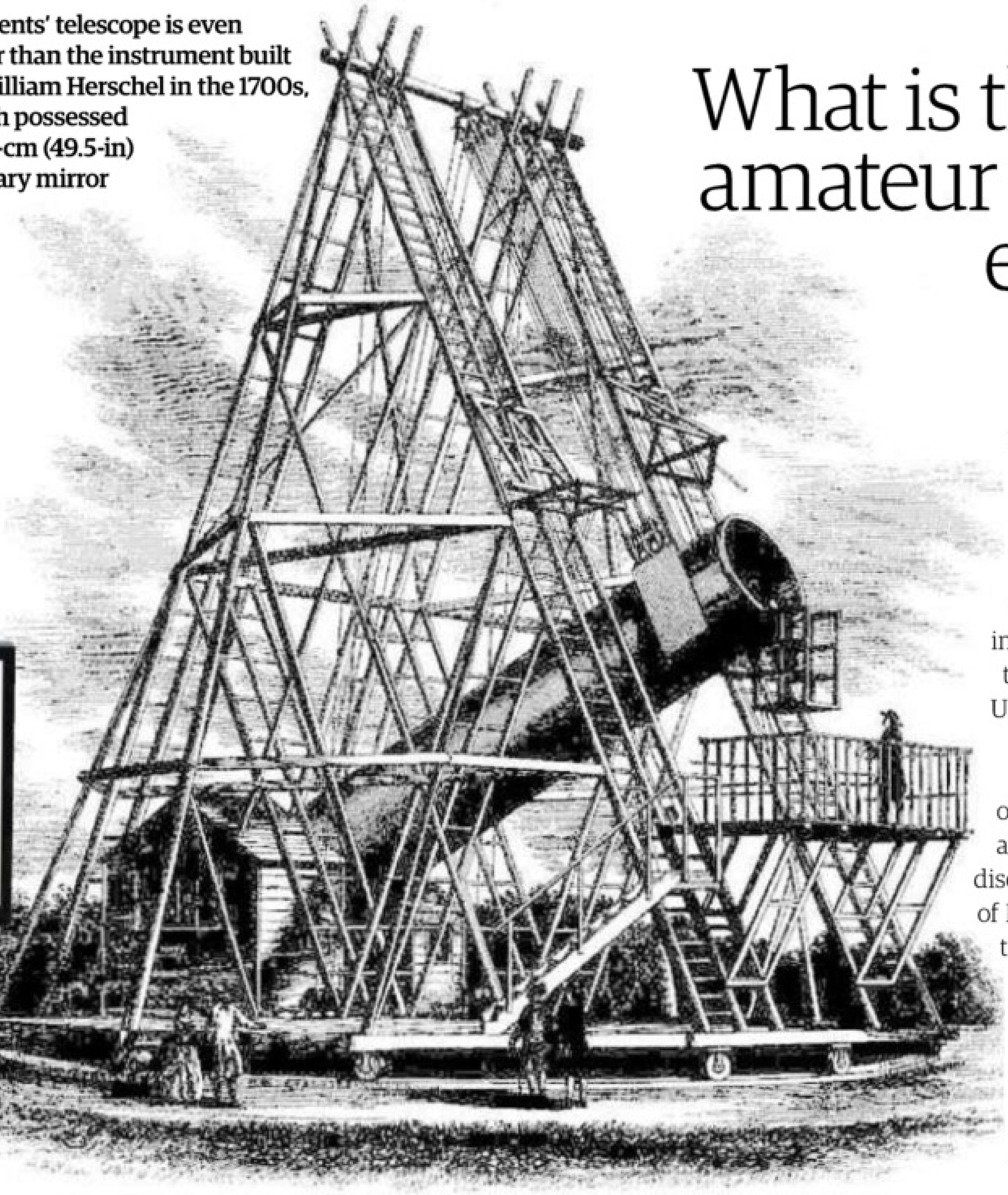
What is the largest galaxy we know of?

Miranda Sacks

Currently the largest known galaxy in our observable universe is believed to be supergiant elliptical galaxy IC 1101, found at the centre of the Abell 2029 galaxy cluster, over one billion light years away. IC 1101 could be up to around six million light years in diameter and houses approximately 100 trillion stars. That's about 400 times as many as our, comparatively tiny, Milky Way galaxy, which reaches around 100,000 light years across.

Elliptical galaxies are clusters of old stars and range from spherical to a squashed ovoid in shape. The rate of star formation is low because they have very little star-forming material left.

It is thought that collisions and coalition of spiral galaxies are responsible for the formation of the massive conglomeration of stars that is an elliptical galaxy. **ZB**



Clements' telescope is even larger than the instrument built by William Herschel in the 1700s, which possessed a 126-cm (49.5-in) primary mirror

ASTRONOMY

What is the largest amateur telescope ever built?

Yasmin Isaacs

While many amateur astronomers would be happy with a moderately-sized 20- to 25-centimetre (eight- to ten-inch) telescope, the largest amateur telescope that has ever been built is a whopping 178 centimetres (70 inches) – currently the largest in the world. Mike Clements from Utah built a telescope that has a mirror that was meant for a Cold War spy satellite. He obtained the mirror through an auction when the mirror wasn't discarded by the U.S. Department of Defense when they discovered that the edge of the mirror was slightly chipped. Clements then built the rest of the telescope from everyday materials, causing it to weigh in at a whopping 1,361 kilograms (3,000 pounds). **GL**

SPACE EXPLORATION

What happened during the Space Race?

Leigh Marklow

A competition between bitter Cold War rivals, the Soviet Union and the United States, the Space Race involved the fight for supremacy to put the first craft into space.

Sparking the first real efforts to launch artificial satellites, unmanned probes to the Moon, Venus and Mars as well as human spaceflight in Earth orbit and the famous Apollo lunar landings, the Space Race took a hold of the years between 1955 and 1972.

In 1955, after hearing the announcement that the United States was intending to launch artificial satellites for the International Geophysical Year, the Soviets responded four days later to say that they too would be launching a satellite in the near future. This sparked the start of one of the most famous periods in space exploration.

The Soviets won the first round when they launched Sputnik 1 in 1957. However, later in 1969, the United States landed the first humans on the Moon before the race concluded when both rivals collaborated on the Apollo-Soyuz Test Project. **GL**

Sputnik 1, as shown in this artist's impression, was launched by the Soviets in 1957

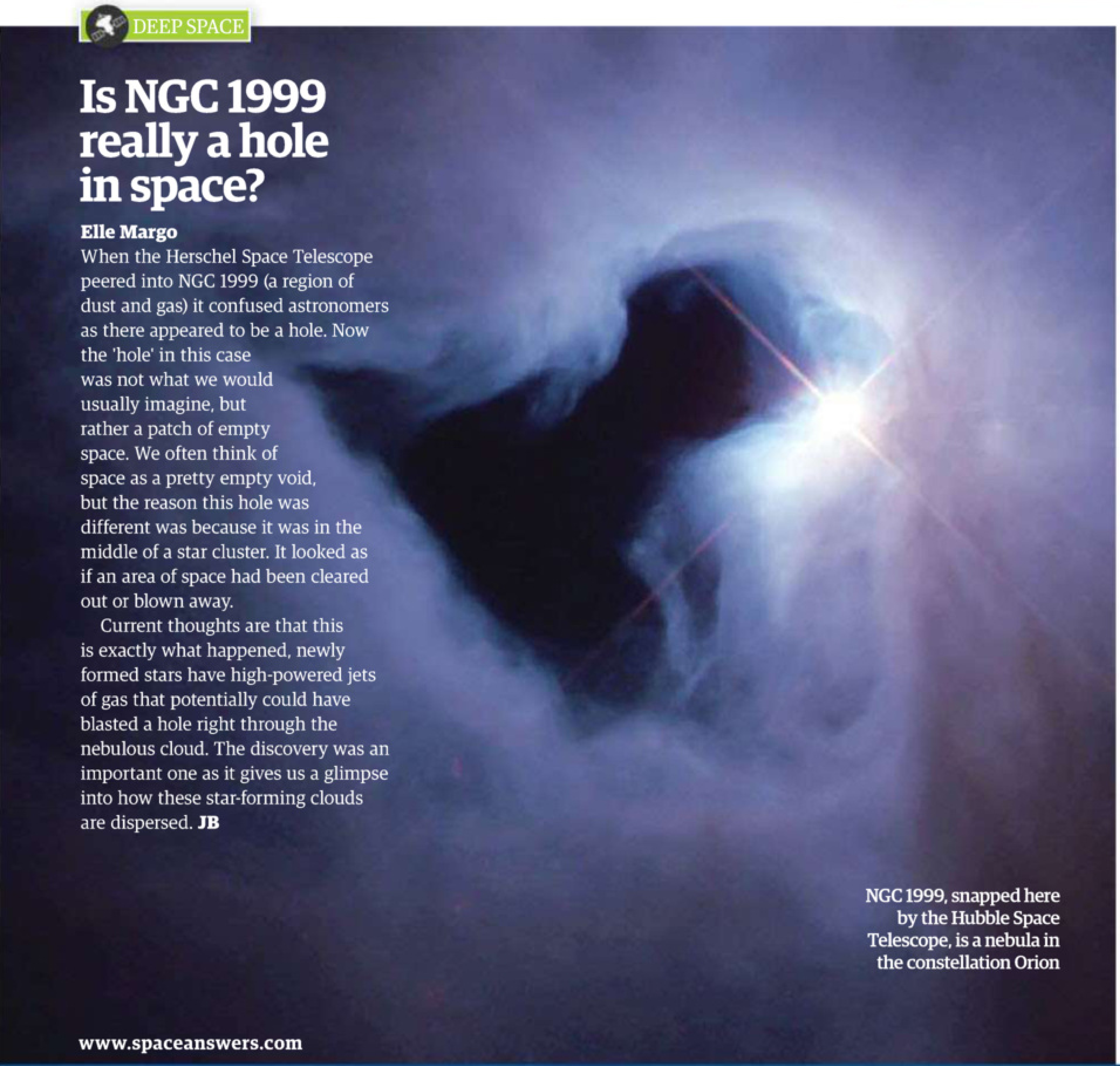
DEEP SPACE

Is NGC 1999 really a hole in space?

Elle Margo

When the Herschel Space Telescope peered into NGC 1999 (a region of dust and gas) it confused astronomers as there appeared to be a hole. Now the 'hole' in this case was not what we would usually imagine, but rather a patch of empty space. We often think of space as a pretty empty void, but the reason this hole was different was because it was in the middle of a star cluster. It looked as if an area of space had been cleared out or blown away.

Current thoughts are that this is exactly what happened, newly formed stars have high-powered jets of gas that potentially could have blasted a hole right through the nebulous cloud. The discovery was an important one as it gives us a glimpse into how these star-forming clouds are dispersed. **JB**



NGC 1999, snapped here by the Hubble Space Telescope, is a nebula in the constellation Orion

Quick-fire questions

@spaceanswers

When will Juno reach Jupiter?

Launched in August 2011, the Juno spacecraft should arrive at the gas giant during July 2016.

What does OSIRIS-REx stand for?

Planned asteroid study and sample return mission, OSIRIS-REx is the acronym for Origins Spectral Interpretation Resource Identification Security Regolith Explorer.

What is the biggest comet we know of?

While astronomers haven't been able to obtain a fully accurate measurement, Comet McNaught (C/2006 P1), or the Great Comet of 2007, is said to be the largest comet to date.

How many stars are there in the universe?

While it's difficult to pin down an exact number, since we're unsure of how big the universe actually is, it's thought that there are 70 thousand million million million stars in the universe.

How long does it take for Venus to complete an orbit?

Since Venus is closer to the Sun than Earth, it takes less time to orbit our star. The planet takes 224.7 days to complete one orbit.

What is a hot Neptune?

This is an exoplanet that not only orbits close to its star, causing it to become heated to high temperatures, but it is also similar in mass to Neptune and in some cases Uranus.

What is the name of India's Mars orbiter?

India's first interplanetary mission to planet Mars, which was launched in November 2013, is known as the Mars Orbiter Mission - or MOM for short.

Quick-fire questions

@spaceanswers

What is the biggest impact crater in the Solar System?

With a diameter of 1,550 kilometres (963 miles), the largest crater in the Solar System is the Caloris Basin on Mercury.

What is meant by Olber's paradox?

Also known as the dark night sky paradox, Olber's paradox argues that if the universe is infinite and there are so many stars, then why isn't the night sky brighter?

Will the New Horizons mission continue beyond Pluto?

That is the plan. Scientists, including the mission's principal investigator Alan Stern, intend for the spacecraft to observe Kuiper Belt Objects.

Is it cold on Saturn?

Saturn's temperature isn't massively uniform throughout its gaseous layers. Its cloud tops are -140 degrees Celsius (-96 degrees Fahrenheit) while the core may reach 11,700 degrees Celsius (21,000 degrees Fahrenheit).

What is a Catadioptric telescope?

These instruments work by combining the best features of refractors and reflector telescopes.

Which type of telescope mount is best for a beginner?

Being light and very easy to use, an Alt-azimuth mount is best for a beginner.

What was the name of the first woman in space?

Soviet cosmonaut and engineer, Valentina Tereshkova, was the first woman to have flown in space when she piloted Vostok 6 in 1963.

SOLAR SYSTEM

Why hasn't gravity rounded off Miranda's jagged surface?

Tony Huntingdon

Uranus' moon, Miranda, is too small for gravity to have rounded off the jagged surface. It is believed that Miranda is an ice moon, with 1,000 times less mass than the Earth's Moon. In its past, tidal heating due to the extremes of its orbit allowed the interior ice to melt, and behave in a similar geological way to the crust and mantle on the Earth. This produced the breathtaking landscape of large ice canyons, rifts and ridges leaving a jagged icy surface. However, with such a low mass, gravitational heating is not enough to melt and round off these edges, so they remain as they are, a legacy of Miranda's more violent past. **SA**

Moon of Uranus, Miranda, has a breathtaking landscape of large ice canyons, rifts and ridges

Some satellites, such as the Hubble Space Telescope, are in a low Earth orbit

SPACE EXPLORATION

Why are some satellites in high Earth orbit while others are in lower orbits?

Jack Holmes

The orbit of a satellite is carefully chosen dependant on the purpose of a satellite. At different orbiting heights, satellites circle around the Earth at different speeds.

At only a few hundred kilometres up, objects in low Earth orbit (LEO) must move very quickly to prevent being dragged back down by gravity. Satellites put into LEO are ones that need to collect or send data all over the Earth as they constantly change their position relative to the planet's surface.

If we do need a satellite that focuses on a certain region, we can choose to place an object at approximately 36,000 kilometres (22,370 miles) away from Earth in a geostationary orbit (GEO). In GEO, a satellite orbits with a speed equivalent to the Earth's rotation allowing a constant view of a single area somewhere along the equator. **ZB**

ASTRONOMY

How can I picture the space telescopes that are currently in Earth-orbit?

Jonathan Warner

Imaging space telescopes and other Earth-orbiting satellites can be done with a multitude of setups, the most common being a telescope and SLR camera. Many Earth-orbiting objects can be seen from the ground using just our eyes and many others if you use some simple enhancements such as binoculars or a telescope. Amateur astrophotography has been a fast growing and widespread endeavour and there are a multitude of resources to help out.

My advice would be to start with some simple 'by eye' observing, maybe look at investing in a good pair of binoculars or small telescope then move to taking a few images. There are many communities online but also local astronomy clubs can be great at introducing you to this hobby. **JB**

Imaging many Earth-orbiting objects will require a good camera such as a DSLR

Questions to... @spaceanswers /AllAboutSpaceMagazine questions@spaceanswers.com

Our night sky would be teeming with many stars if we were living inside a globular cluster

DEEP SPACE

What would it be like to live in a globular cluster?

Terry White

If we were able to put our planet around the Sun and put it straight in the middle of a globular star cluster, like 47 Tucanae, our night sky would be teeming with many stars.

In the case of 47 Tucanae, which has millions of members, stars would still appear as points of light since, due to their distance, they would not have diameters that are easily resolved by the human eye. They would also be more than a thousand times brighter than Earth's nighttime star, Sirius.

To live on an Earth in a globular cluster would mean that the cluster's stars (if they were like our Sun) would combine to create a night sky at around 20 times brighter than Earth's night sky at full Moon. **GL**

SOLAR SYSTEM

Could our Sun have a companion star?

Ellie Cope

According to theorists, such as Richard Muller of the University of California at Berkley, it might be possible that our Sun has a companion. However, no concrete evidence has been found to indicate its existence.

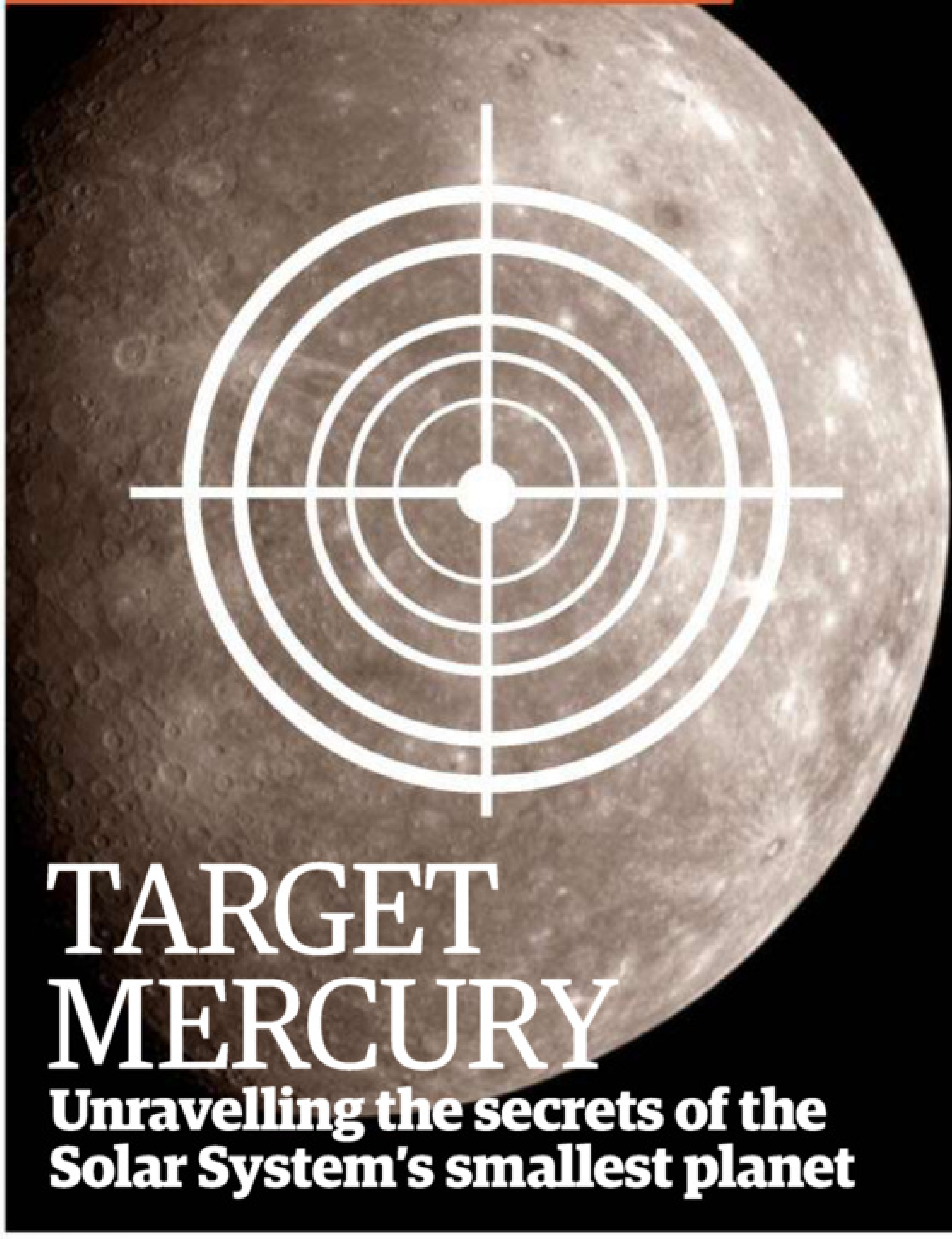
In the early 1980s Muller, alongside several other leading scientists of the time, noticed that extinctions on our planet seemed to fall in a specific pattern and occurred more frequently every 26 or 27 million years.

The speculated companion - called Nemesis - is thought to either be a brown dwarf of a dwarf star, which in its orbit, disturbed debris from the Kuiper belt or comets from the Oort Cloud, sending them hurtling towards Earth. **GL**

Does our Sun have a 'nemesis'?

© NASA; NASA/Swift/Cruz deWilde Alamy; David A. Aguilar (CfA)

Next Issue

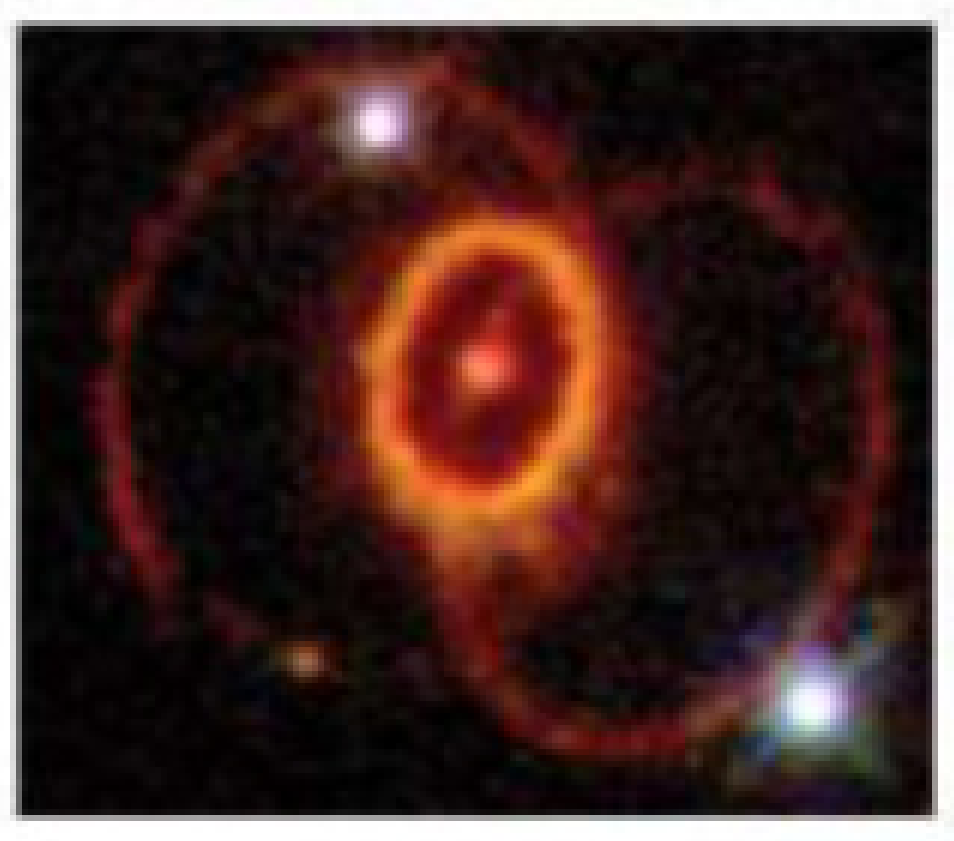


TARGET MERCURY

Unravelling the secrets of the Solar System's smallest planet

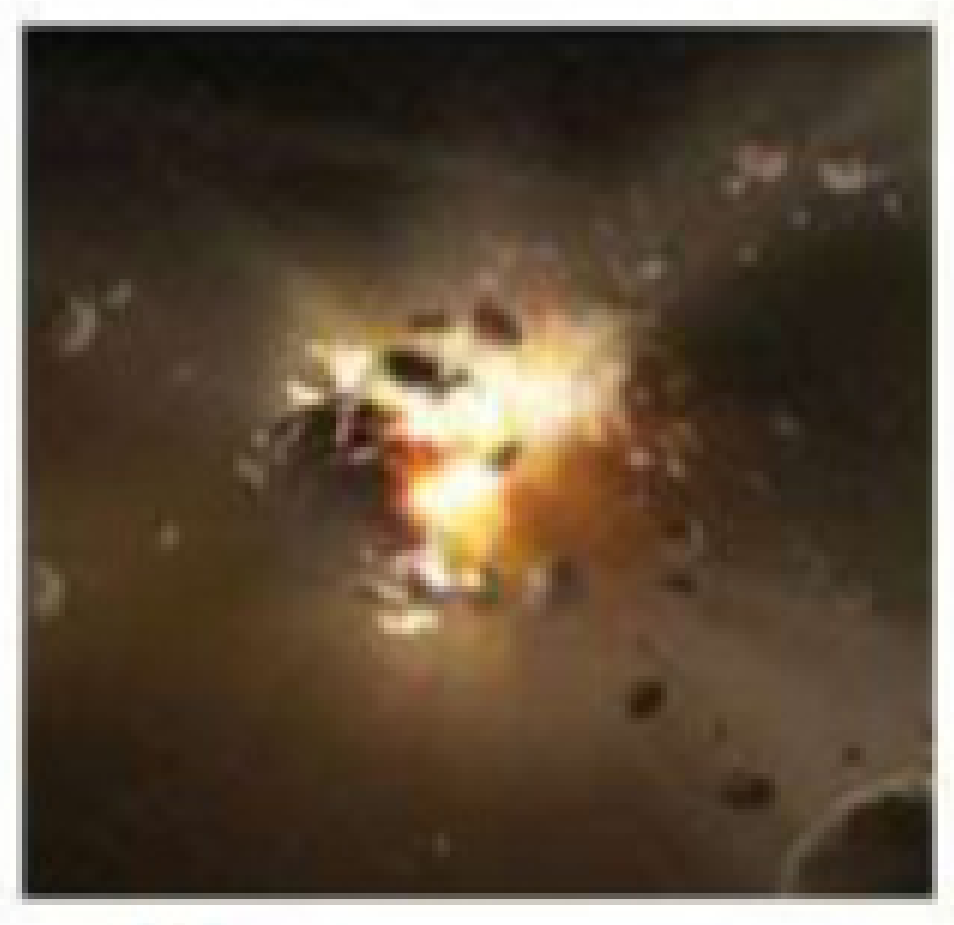
LIFE ON ALIEN MOONS

The people searching the Milky Way for a trillion tiny worlds



EARTH'S CLOSEST SUPERNOVA

All About supernova 1987A, the star that shouldn't have exploded



10 COLOSSAL COSMIC COLLISIONS

Discover jaw-dropping space impacts that shook the foundations of physics

In orbit 21 Aug 2014

+

BIO SPACESUIT
THE TORINO SCALE
NASA'S FLYING SAUCER
RELATIVITY DRIVE PROPULSION
HOW TO SEE SUMMER NEBULAS
BIGGEST OBJECTS IN THE SOLAR SYSTEM

STARGAZER
GUIDES AND ADVICE TO GET STARTED IN AMATEUR ASTRONOMY

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Spotting scope astronomy

Often overlooked, these compact scopes provide a cheap alternative to telescopes for basic astronomy

Spotting scopes: the nature-watcher's ultimate piece of equipment, equally useful for studying a herd of antelope in Africa or a bird flitting from tree to tree in the countryside. When day turns to night, these observers of nature head home, as there's nothing else to see in the low light. Meanwhile, the astronomer is just getting ready to head into the dark with the planets and stars peppering clear moonlit skies. Rather than lug their heavy telescopes to that perfectly dark spot, however, enthusiasts often favour spotting scopes to easily glimpse the wonders of the night sky.

This is a scene not many are familiar with. When we picture astronomers we see an individual wrapped up in warm clothing and huddled over the eyepiece of an attention-grabbing Dobsonian telescope, or a trustworthy refractor. However, just like a nature-lover, astronomers also like to use spotting scopes - especially for quick and easy astronomy sessions.

It's true that these compact scopes won't give you detailed views of deep-sky objects such as galaxies and nebulas - at least, not the same sights that a decent telescope will provide. However, what you will get are surprisingly good views of brighter objects including the Moon, nearby planets and open clusters, under the right conditions.

When it comes to power, spotting scopes are supplied with zoom eyepieces that reach magnifications of up to 60x and often higher. These can be removed to make way for standard eyepieces that are used by conventional astronomical telescopes. For night-sky observations, a power of at least 60x is a must, however, you have to be mindful of your spotting scope's aperture. This is the diameter of your device's objective lens - the bigger it is, the more light your instrument will be able to collect and the more enriched your observing experience will be.

The beauty of the night sky means that many observers want to capture it with cameras. Luckily most spotting scopes generally accept a variety of digital cameras that can be affixed using special adapters. However, when it comes to digiscoping, your device's stability on its tripod combines with the fact that many night-sky objects are mere pinpoints on a sea of black - making viewing problematic.

Low brightness means that the shutter speed for your camera has to be quite slow and, as such, you must ensure that movement and vibrations are kept to a minimum to obtain a clear picture. A solid and suitable mount to capture your target is essential. Additionally, focusing requires a degree of experimenting, since the small viewing screen on a digital camera, combined with the dimness of a night-sky object, can provide a challenge.

Due to the fact that they are portable, have an ability to capture clear images and that they are often several hundreds of pounds cheaper than a standard telescope, the spotting scope has become an increasingly common presence on the astronomy scene. ■

Spotting scopes are smaller and so far easier to set up than telescopes

Eyepieces
The more-advanced spotting scopes come with a zoom eyepiece that can often be removed and, combined with the scope's focal length, will provide your magnification.

How to choose a spotting scope

- ✓ The larger the objective lens, the better. If you are on a budget, then you are best off buying a higher-quality telescope with a smaller objective lens.
- ✓ Think about what you'll use your spotting scope for. If you are looking to observe deep-sky objects and won't use the spotting scope past astronomy, then you're better off buying a conventional telescope.
- ✓ You should always consider the weight of a spotting scope. If you're looking for something suitable for travel, then the lighter the better.
- ✓ There should be coating on the lenses to ensure there's no light loss and to reduce glare from reflection. This usually means the scope will produce brighter, clearer images.
- ✓ If you wear glasses, then special attention to eye relief is a must. This is the distance between the eye lens and the point where the pupil is positioned over the full field of view.
- ✓ Buy your spotting scope from a reputable dealer - they will be able to offer you advice in picking the correct spotting scope for you.

WIN! An Olivon T650 spotting scope outfit!
Turn to page 95 for details on how to enter

The astronomer's spotting scope

"The spotting scope has become an increasingly common presence on the astronomy scene"

Gathering light
A spotting scope has a large, multi-coated, objective lens, so it can gather much more light. This makes the device especially useful in low-light conditions.

Angled or straight?
Straight spotting scopes are much easier for beginners to use for terrestrial viewing. An angled scope (with an eyepiece positioned at 45 or 90 degrees) is much better for astronomy, as these can be mounted and easily pointed skywards.

Water resistance
Telescopes aren't massively water-resistant because they're used under clear skies. However, spotting scopes are often used in the rain by nature-watchers, which means they must be highly fog- and water-resistant.

Digiscoping
It's possible to photograph the night sky by attaching a digital camera, though getting a decent image takes much trial and error.

Bright targets
To get the brightest objects in the night sky, such as the Moon, planets and open clusters, you will need a magnification of at least 60x.

Tripod
The beauty of a spotting scope is that it can be used with or without a tripod. However, if you're using your scope for astronomical purposes, it's strongly recommend mounting the scope on a sturdy tripod.

Short cool-down
Many astronomers complain about the cool-down time of their telescopes. Since spotting scopes are so compact and lightweight, they have a short cool-down time, making them ready to use almost immediately.

Olivon T650 spotting scope

Aperture: 65mm
Magnification: 16-48x zoom eyepiece (removable)
From: www.opticalhardware.co.uk
Cost: £240

Meteor shower viewing

Speeding through the atmosphere at thousands of kilometres per hour, meteor showers offer an exciting view for stargazers

If you enjoy gazing up at the stars on a clear night, you might have seen what looks like a point of light streaking across the sky. "Did you see that? I just saw a shooting star," you might have said to a fellow observer. Technically of course these are not stars, but meteors, and they are often so fast and sporadic that your companion is likely to have missed your observation.

Meteors are made when a piece of space debris called a meteoroid, micrometeoroid or space dust burns up in Earth's atmosphere. A streak of light can be seen when this happens, due to the glow of the fragmenting object and the trail of burning particles that it leaves in its wake. Meteors can be seen racing across a clear sky during any time of the night and from any location. A single meteor is unpredictable, so to spot one often creates a wave of excitement. During certain times of the year, meteors can appear in huge groups, raining one after the other through our atmosphere in their hundreds, in what are known as meteor showers.

These events occur roughly during the same time every year, as Earth periodically moves through the dusty trail left behind by an active or extinct comet. These showers also originate from the same point in the sky, a radiant located within or near a constellation that earns the meteor shower its name. Head out in chilly November to catch the Leonids racing from the constellation Leo or, if you prefer the warmer nights, the Perseids will offer good views in August, hailing from constellation Perseus.

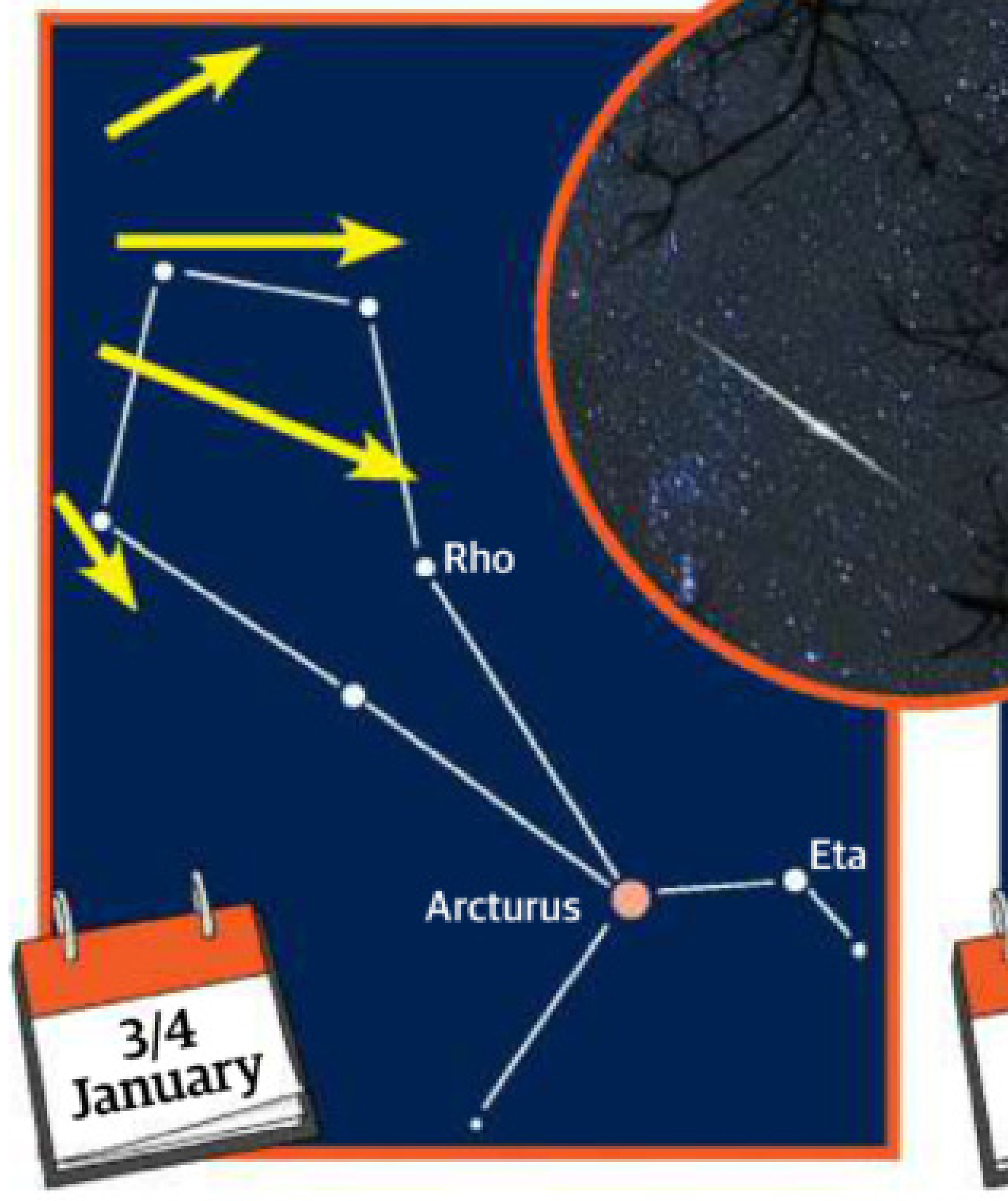
Many astronomers take great interest in recording meteor shower numbers, so you might like to report your observations – including details of their brightness, speed and colour – to official bodies such as the International Meteor Organization (IMO) and International Astronomy Union (IAU). To truly get the benefit of meteor-watching, you will need dark-adapted vision as well as a clear Moonless night to catch even the faintest streaks of light. However, that's not to say you won't see any meteors while the Moon is out – you're most likely to spot the brightest of the pack.

There are also the exceedingly bright meteors, often hitting magnitudes greater than those of the planets in the night sky. These are fireballs or, if they are brighter than magnitude -14, they are known as bolides or superbolides.

> "These are known as fireballs, bolides or superbolides"

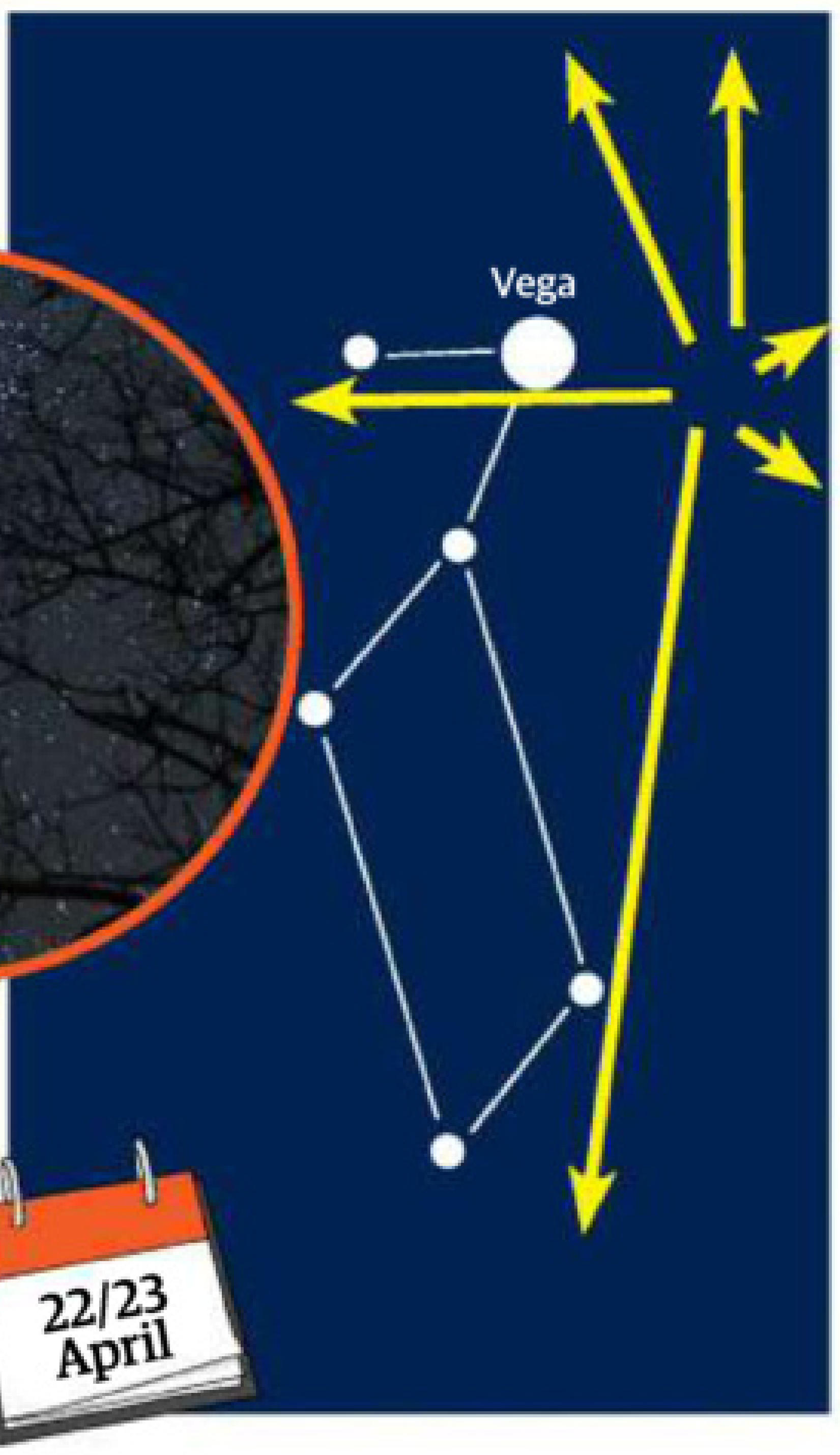
When you picture a meteor shower, you may wrongly think of many meteors bursting out of a single point. Viewing a meteor shower requires a degree of patience, so hunting for these flashes of light turns into a waiting game. The Zenithal Hourly Rate (ZHR) indicates the number of meteors that will appear, with some showers ranging anywhere from five to 100 per hour. When a shower reaches its peak, you might find the amount you see varies – not knowing what you'll get until you begin hunting for meteors is part of the fun. ■

Catch a meteor



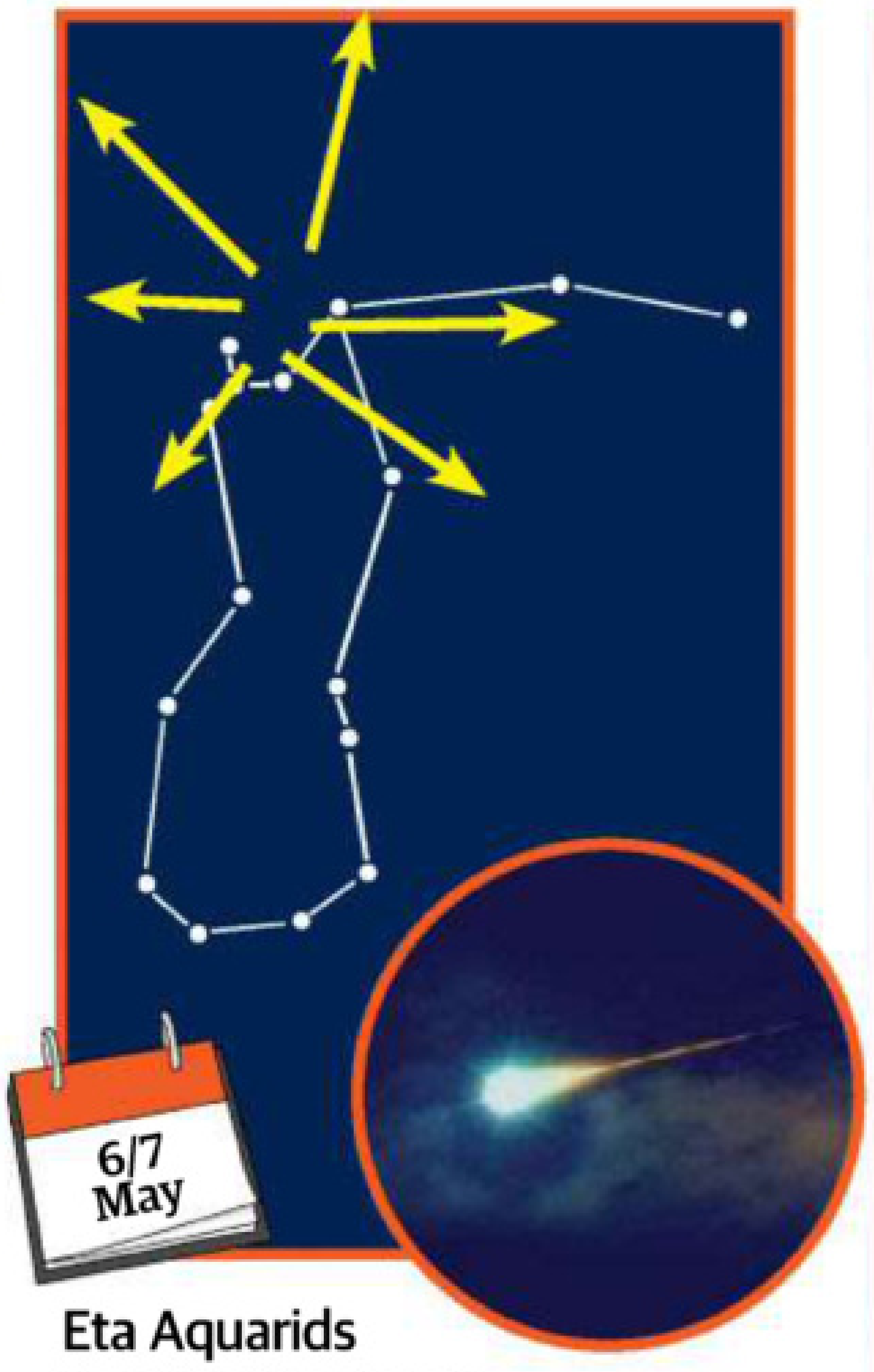
Quadrantids

Constellation: Boötes
ZHR: 80 per hour
Parent asteroid: 2003 EH1



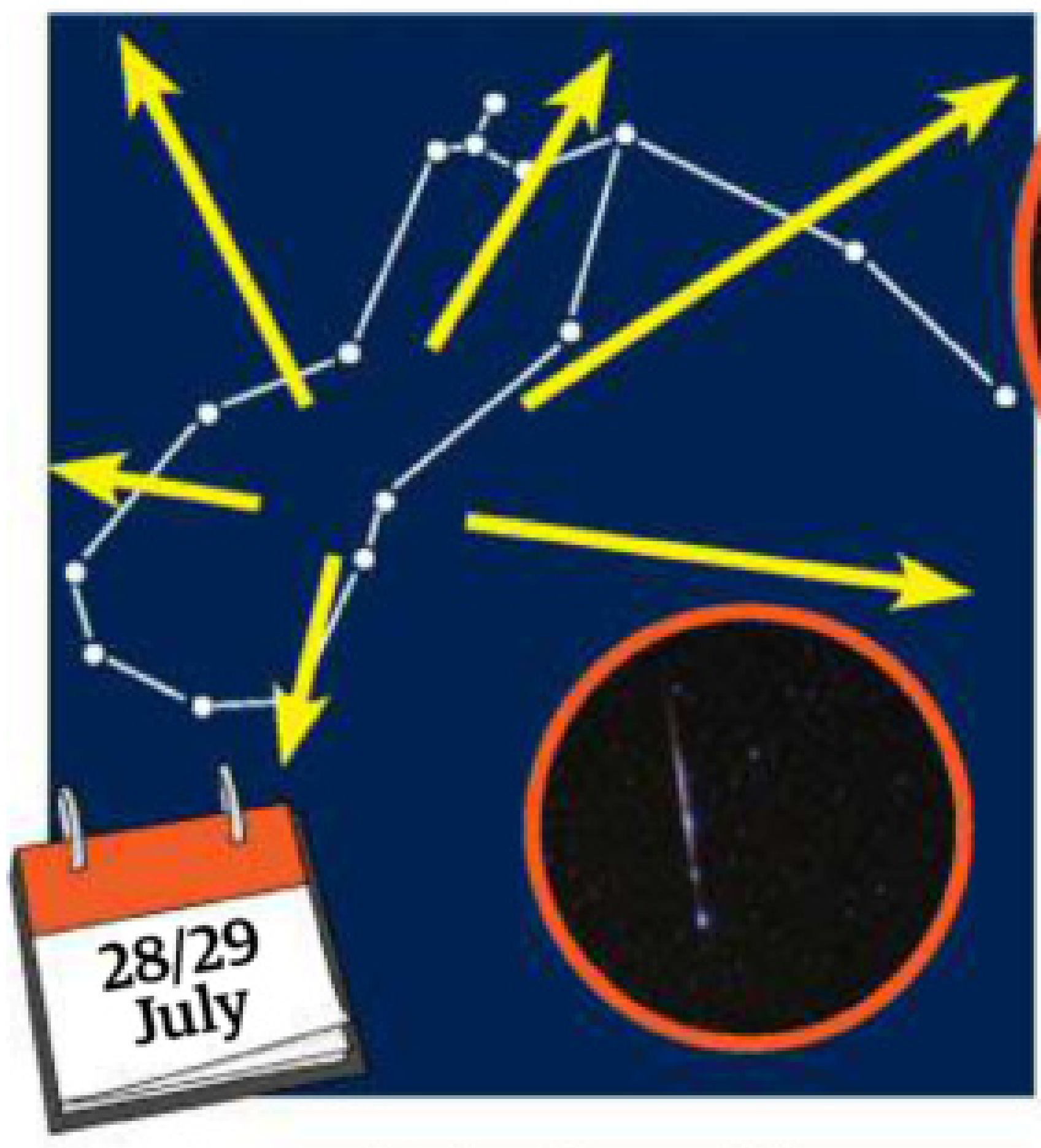
Lyrids

Constellation: Lyra
ZHR: 20 per hour
Parent comet: C/1861 G1 (Thatcher)



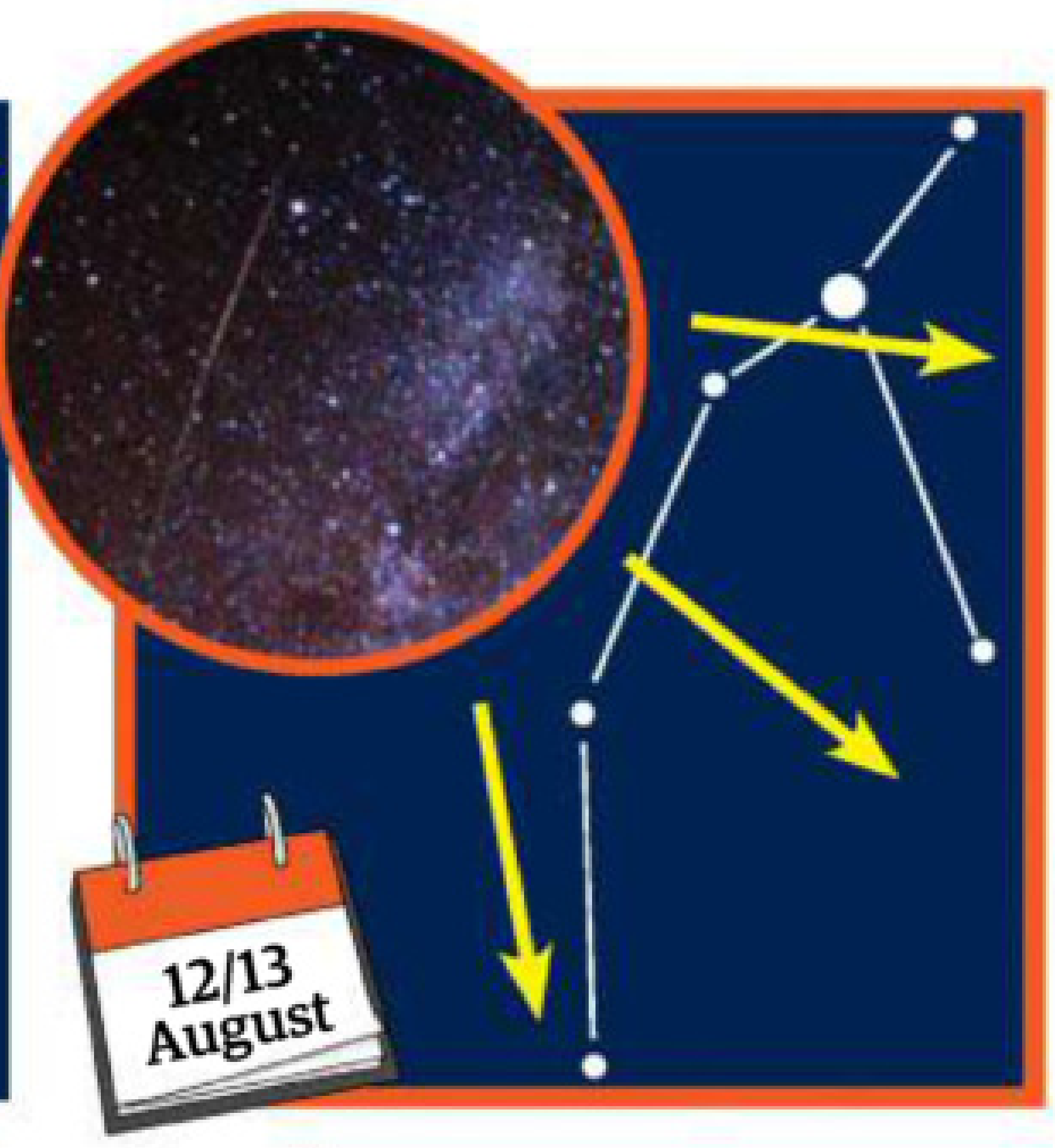
Eta Aquarids

Constellation: Aquarius
ZHR: 45 per hour
Parent comet: Halley



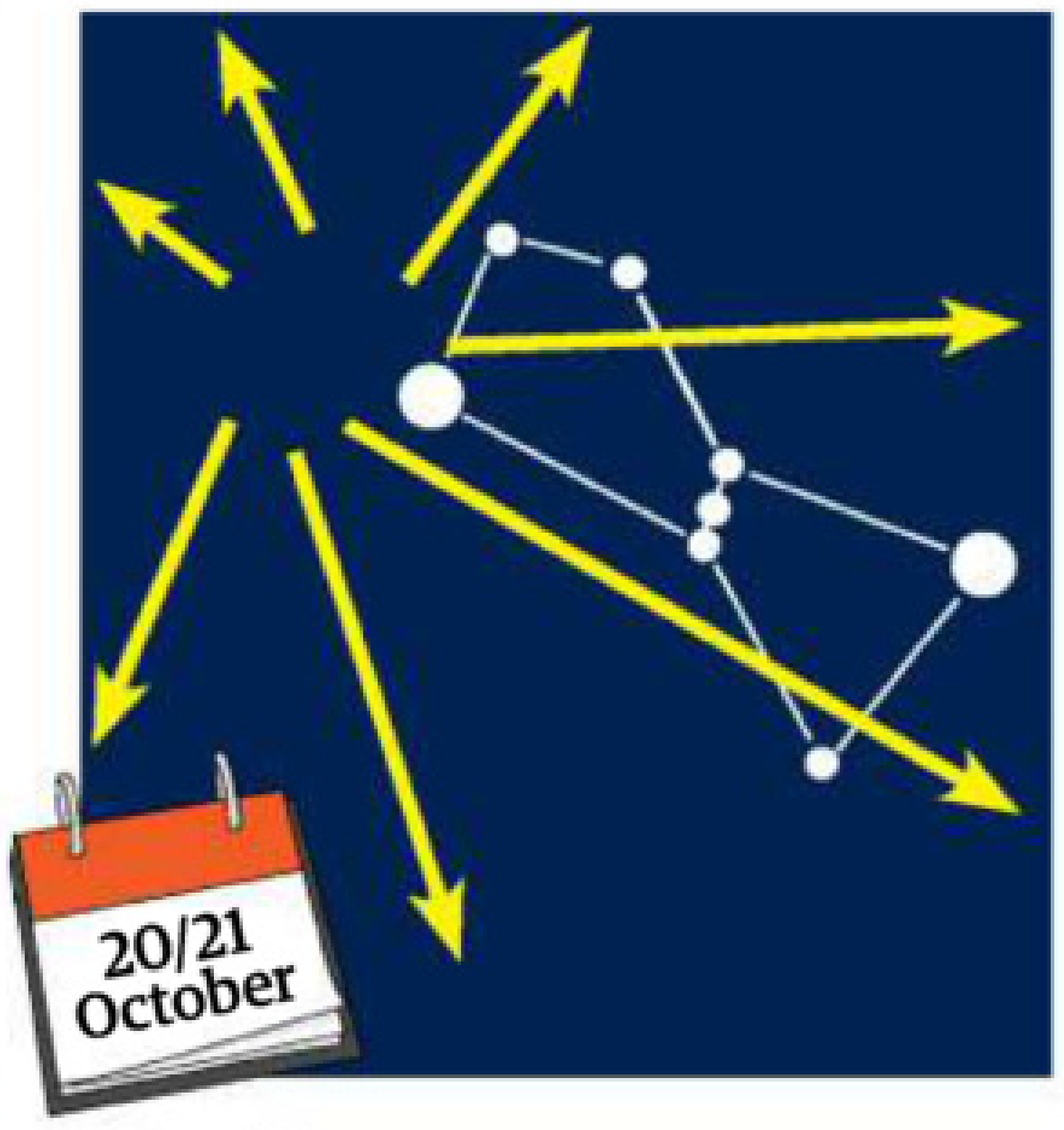
Southern Delta Aquarids

Constellation: Aquarius
ZHR: 20 per hour
Parent comet: Unknown



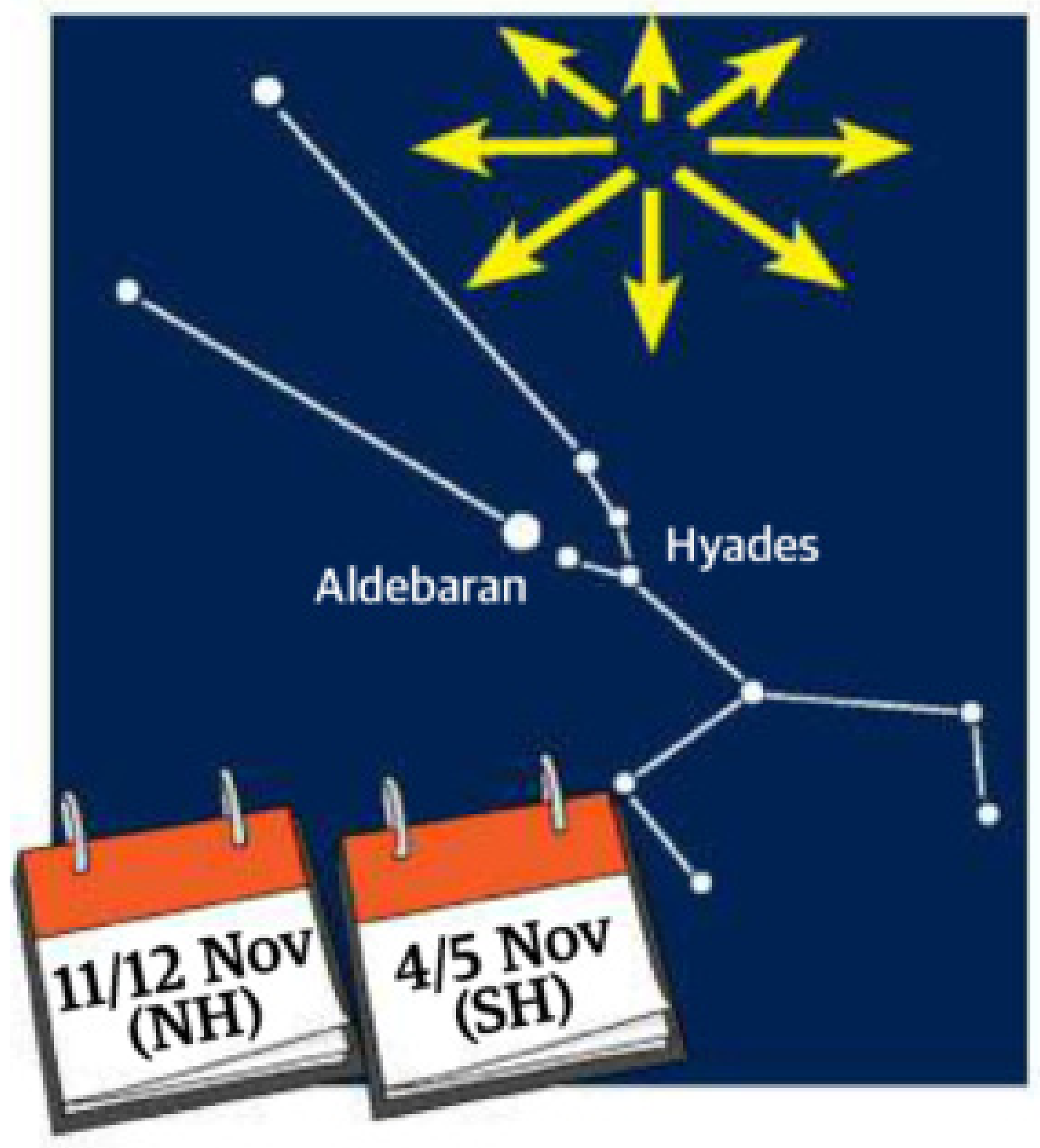
Perseids

Constellation: Perseus
ZHR: 100 per hour
Parent comet: Swift-Tuttle



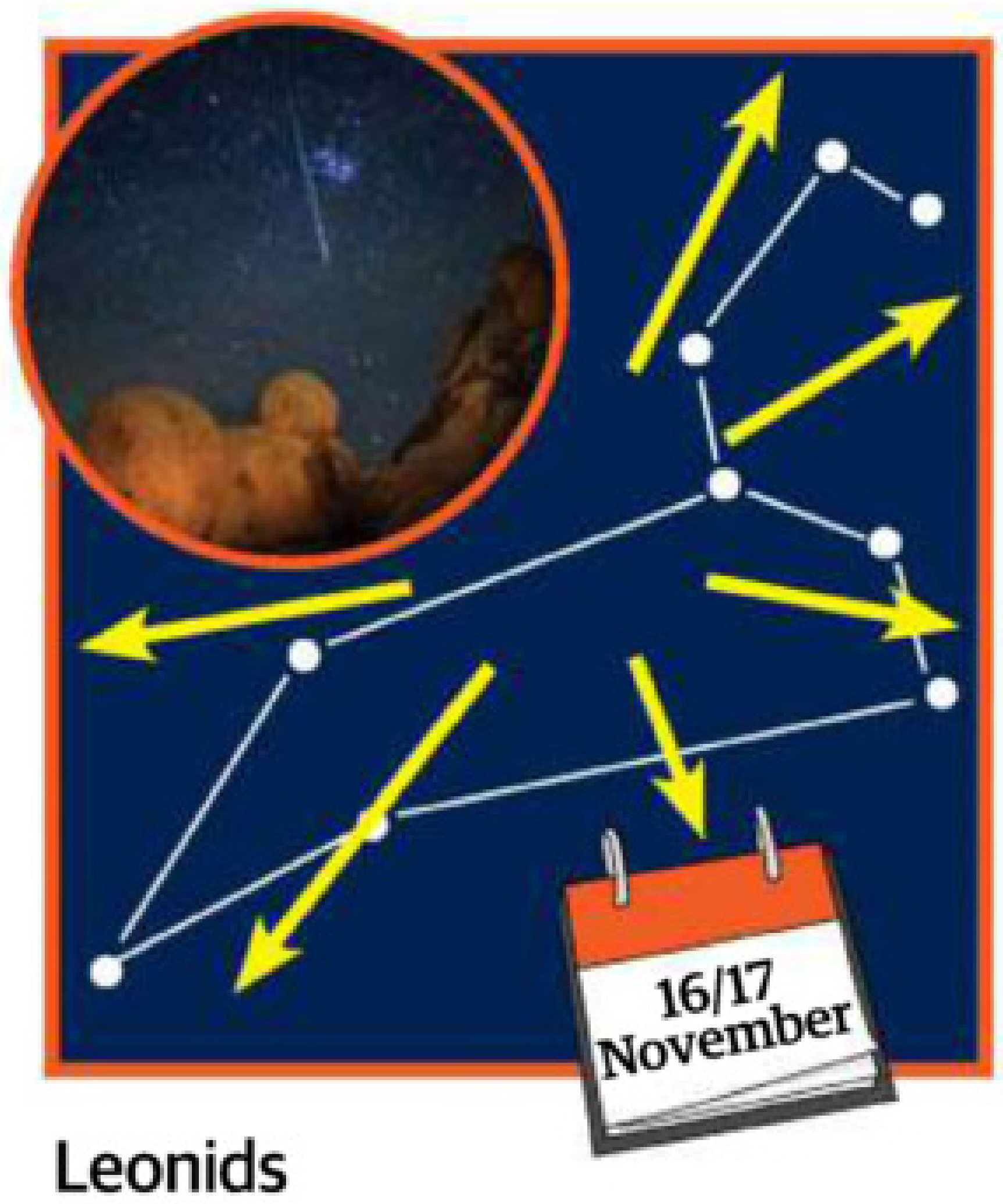
Orionids

Constellation: Orion (The Hunter)
ZHR: 20 per hour
Parent comet: Halley



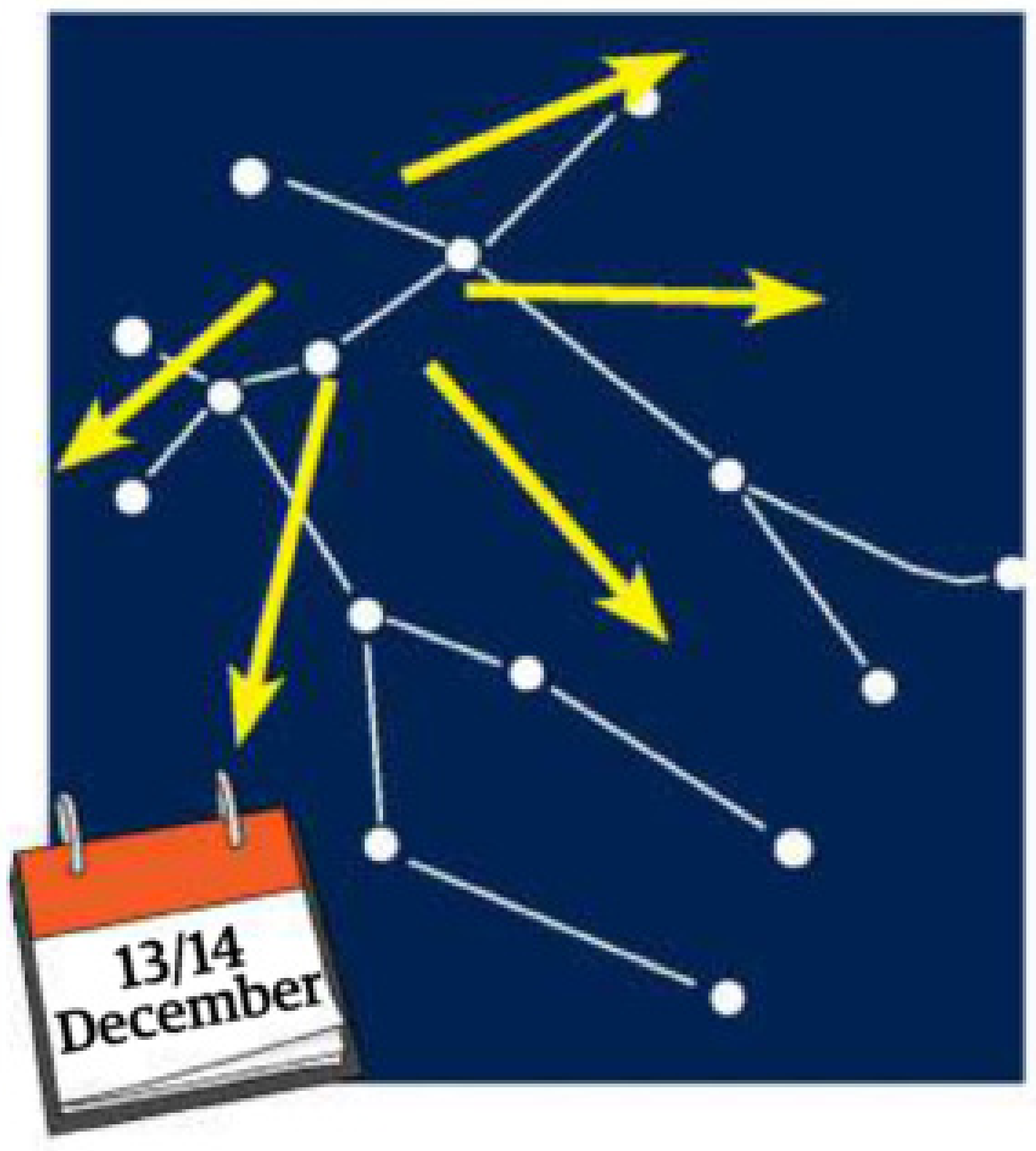
Taurids

Constellation: Taurus (The Bull)
ZHR: 5 per hour
Parent comet: 2P/Encke



Leonids

Constellation: Leo (The Lion)
ZHR: 15
Parent comet: 55P/Tempel-Tuttle



Geminids

Constellation: Gemini (The Twins)
ZHR: 120 per hour
Parent asteroid: 3200 Phaethon

Meteor-hunting toolbox

Deck chair

Hunting for meteors will involve a considerable amount of time looking up, which can strain the neck. A deck chair will keep you at an inclined position for maximum comfort – and without stressing your neck!

Warm clothing

Some showers are only observable during the winter months, so you'll need to make sure you keep warm. A hat, scarf, gloves, along with a thick coat are essential for long periods of observing – you may also wish to use a sleeping bag.

Hot drink

On cold nights it's also a good idea to keep warm by drinking hot liquids. Coffee and tea are often a popular way to keep awake after midnight (though we prefer a hot chocolate). If you can, have a nap before heading out.

Red flashlight

To be able to see the fainter meteors your eyes will need to be adapted to the dark. If you are using a night-sky map or need to see in the dark, then you should use a red torch since the light will not ruin your night vision.

© Corbis; NASA/ Pierre Martin; ESA; H Hubble site

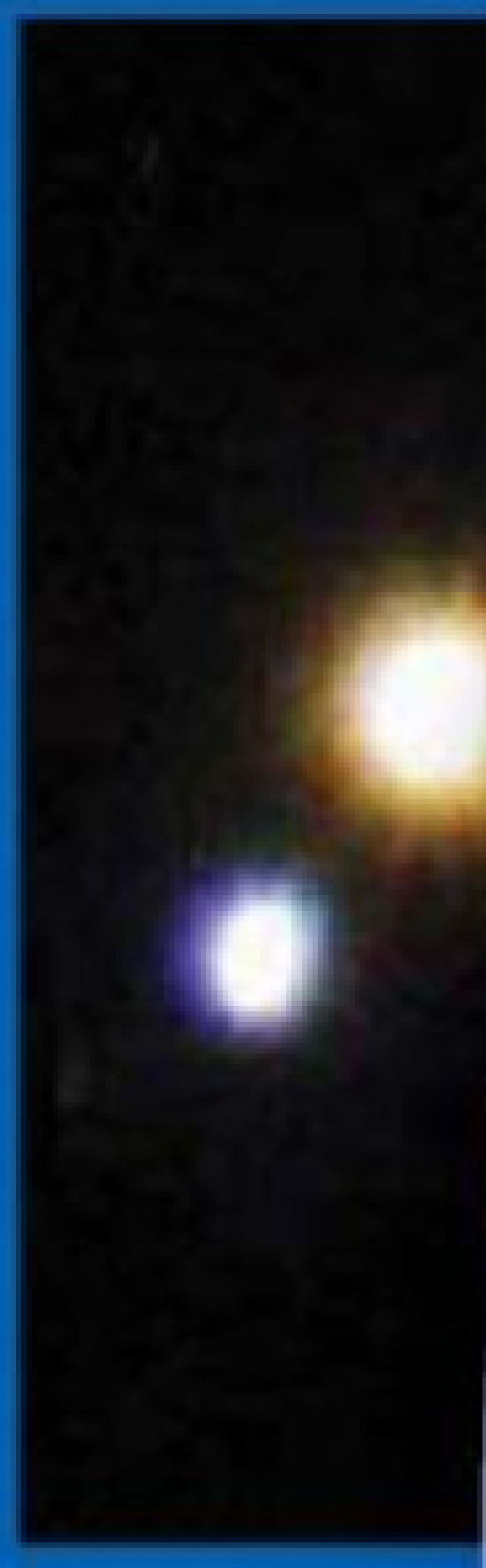
What's in the sky?

Darkness is fleeting in the Northern Hemisphere summer, but there's still plenty to see if you're prepared to stay up late

Albireo

Viewable time: Throughout the night

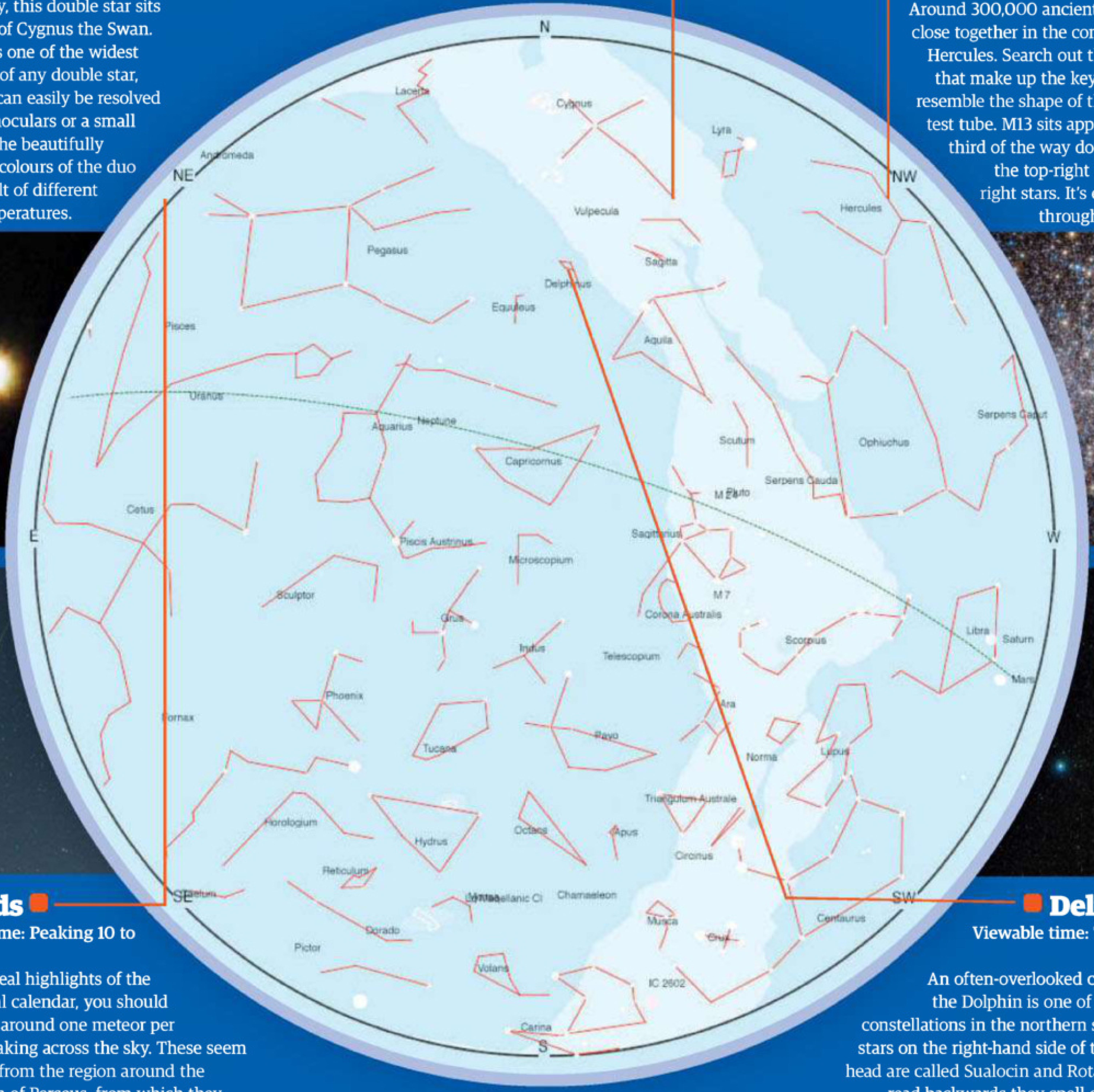
Sometimes called the Jewel of the Summer Sky, this double star sits at the beak of Cygnus the Swan. The duo has one of the widest separations of any double star, meaning it can easily be resolved in either binoculars or a small telescope. The beautifully contrasting colours of the duo are the result of different surface temperatures.



Globular star cluster M13

Viewable time: Throughout the night

Around 300,000 ancient stars nestle close together in the constellation of Hercules. Search out the four stars that make up the keystone – they resemble the shape of the bung in a test tube. M13 sits approximately a third of the way down between the top-right and bottom-right stars. It's easily visible through binoculars.



Northern Hemisphere

Perseids

Viewable time: Peaking 10 to 13 August

One of the real highlights of the astronomical calendar, you should look out for around one meteor per minute streaking across the sky. These seem to emanate from the region around the constellation of Perseus, from which they get their name. A bright Moon is likely to be around too, however, which could perhaps obscure some of the dimmer shooting stars from full view.

Delphinus

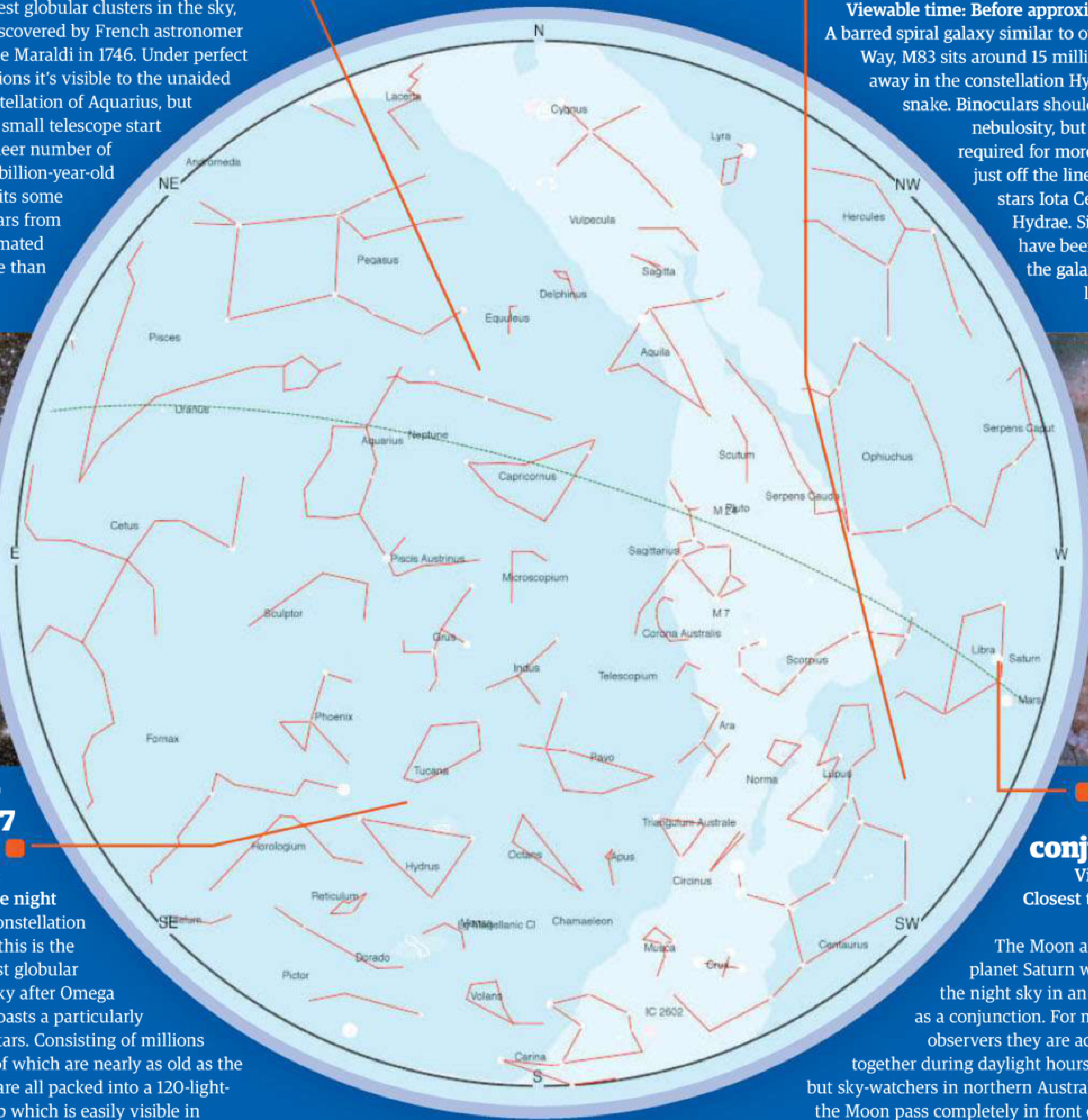
Viewable time: Throughout the night

An often-overlooked constellation, the Dolphin is one of the smallest constellations in the northern sky. The two stars on the right-hand side of the dolphin's head are called Sualocin and Rotanev – when read backwards they spell out the Latin name of the former deputy director of the Palermo Observatory in Sicily. This is because technically you're not supposed to name stars after yourself.

Globular star cluster M2

Viewable time: Throughout the night

One of the largest globular clusters in the sky, M2 was first discovered by French astronomer Jean-Dominique Maraldi in 1746. Under perfect viewing conditions it's visible to the unaided eye in the constellation of Aquarius, but binoculars or a small telescope start to reveal the sheer number of stars in this 13 billion-year-old cluster which sits some 37,500 light years from Earth. It is estimated to contain more than 100,000 stars.

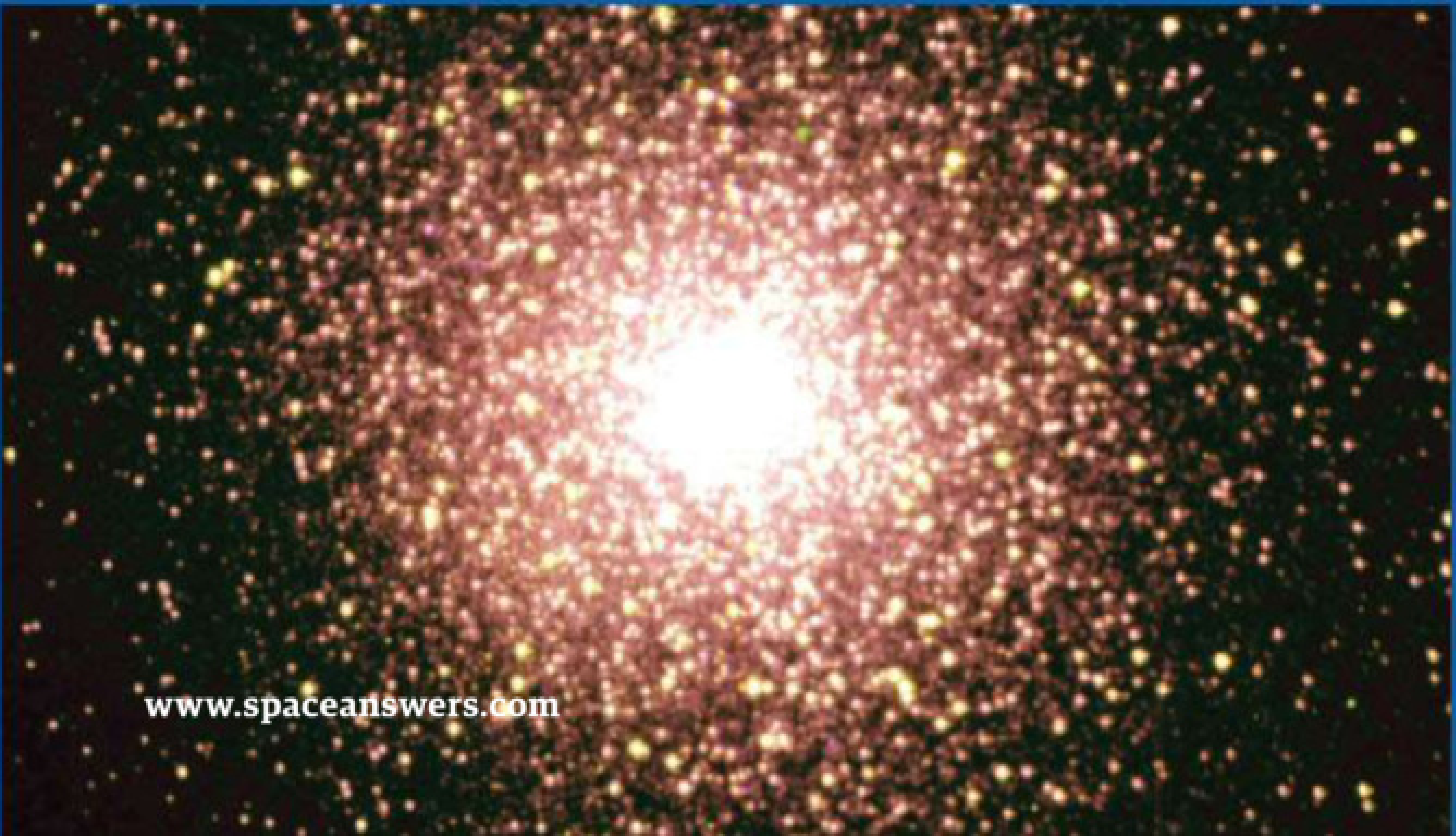


Southern Hemisphere

Globular cluster 47 Tucanae

Viewable time: Throughout the night

Found in the constellation of the Toucan, this is the second-brightest globular cluster in the sky after Omega Centauri and boasts a particularly dense core of stars. Consisting of millions of stars, some of which are nearly as old as the universe, they are all packed into a 120-light-year-wide group which is easily visible in binoculars or a small telescope. The Hubble Space Telescope once probed the cluster for planets, but without success.



Southern Pinwheel galaxy, M83

Viewable time: Before approximately 10pm

A barred spiral galaxy similar to our own Milky Way, M83 sits around 15 million light years away in the constellation Hydra the water snake. Binoculars should reveal some nebulosity, but a telescope is required for more detail. It sits just off the line between the stars Iota Centauri and Pi Hydrae. Six supernovas have been observed in the galaxy within the last 100 years.

Moon/ Saturn conjunction

Viewable time: Closest together on 4 August

The Moon and the ringed planet Saturn will cosy up in the night sky in an event known as a conjunction. For most southern observers they are actually closest together during daylight hours on 4 August, but sky-watchers in northern Australia should see the Moon pass completely in front of Saturn - an occultation. This is just one of the 11 Moon/Saturn occultations to occur in 2014.

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Me & my telescope

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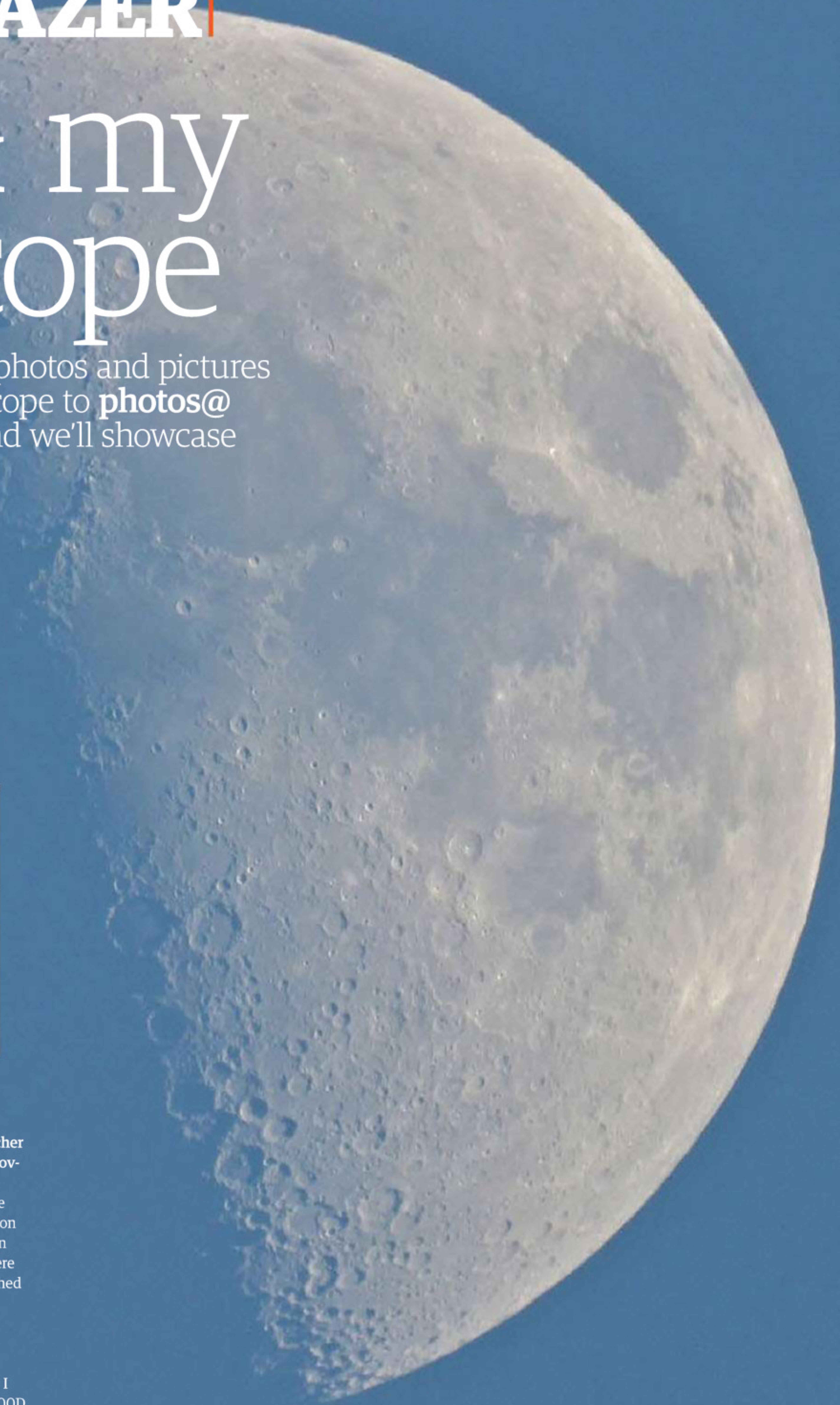
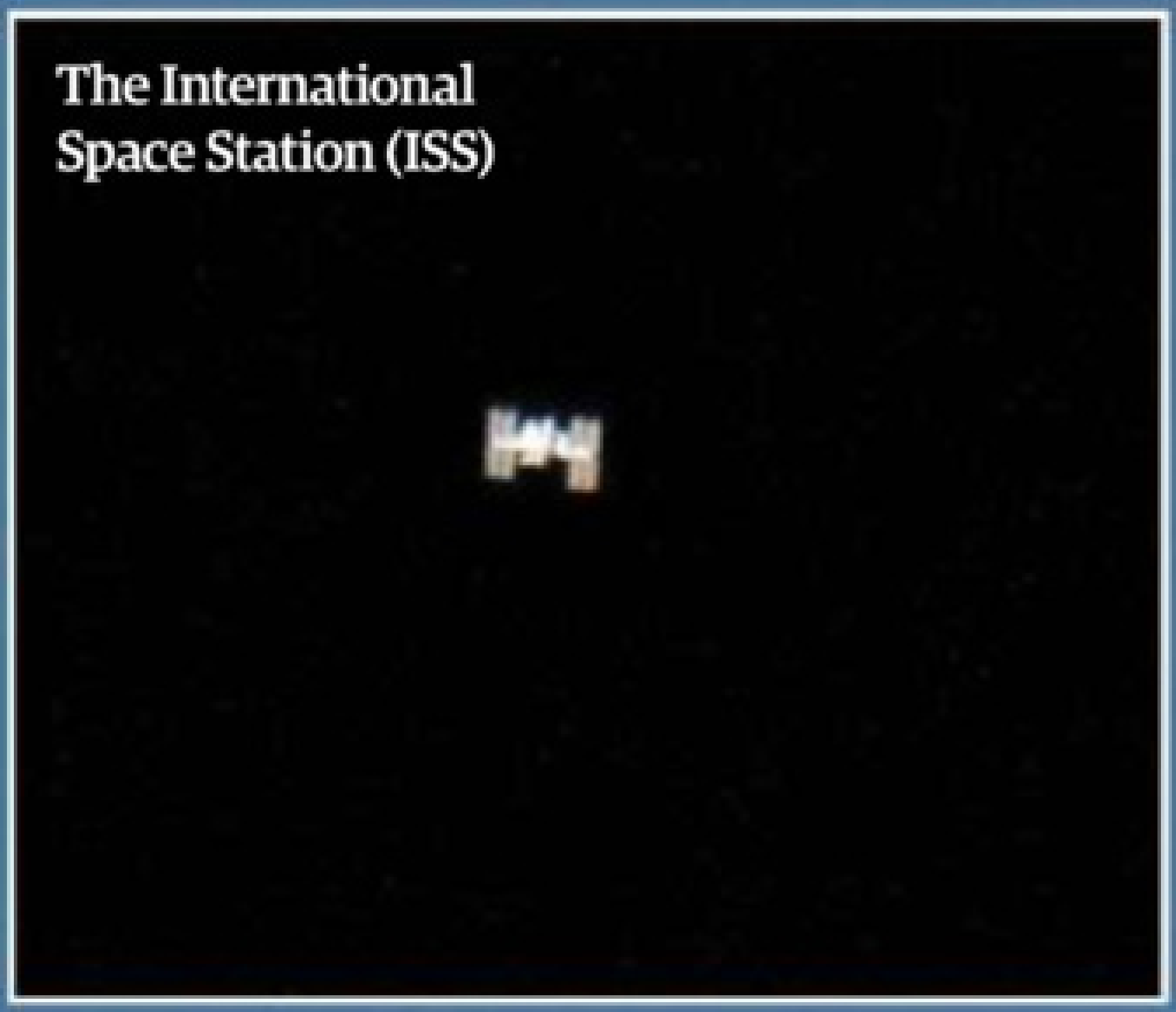
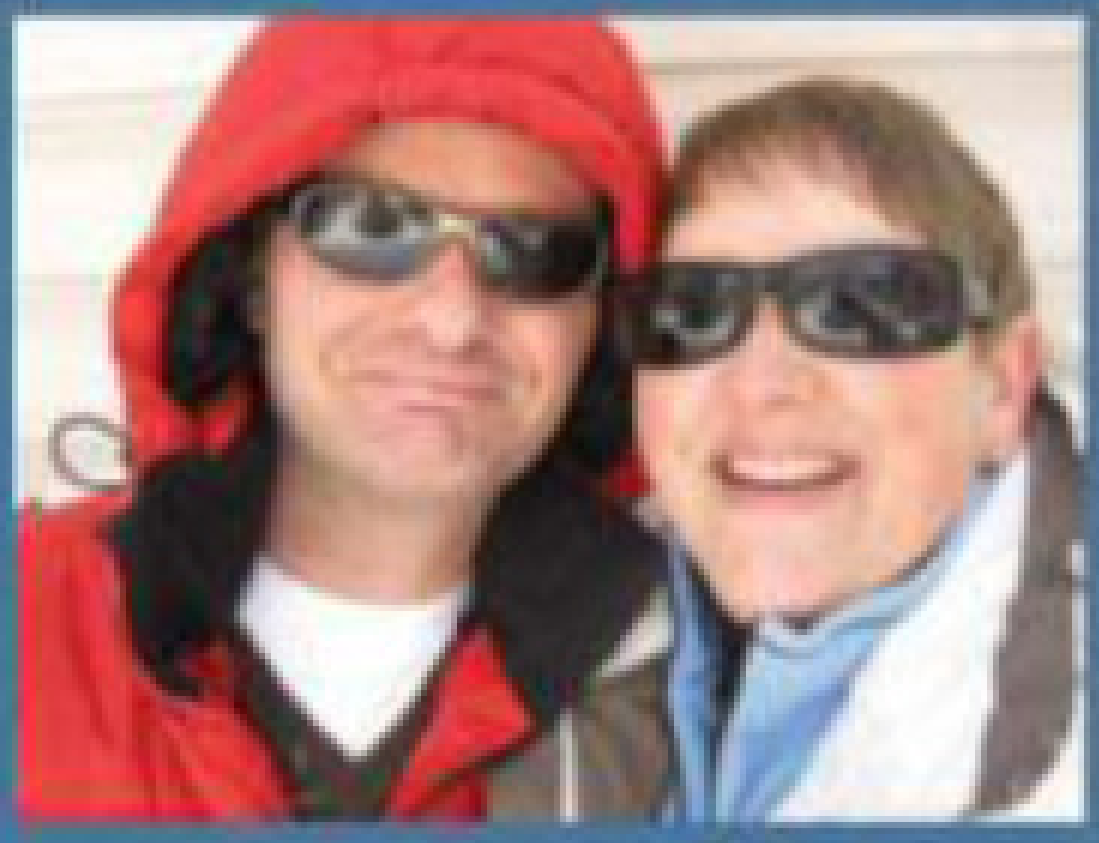




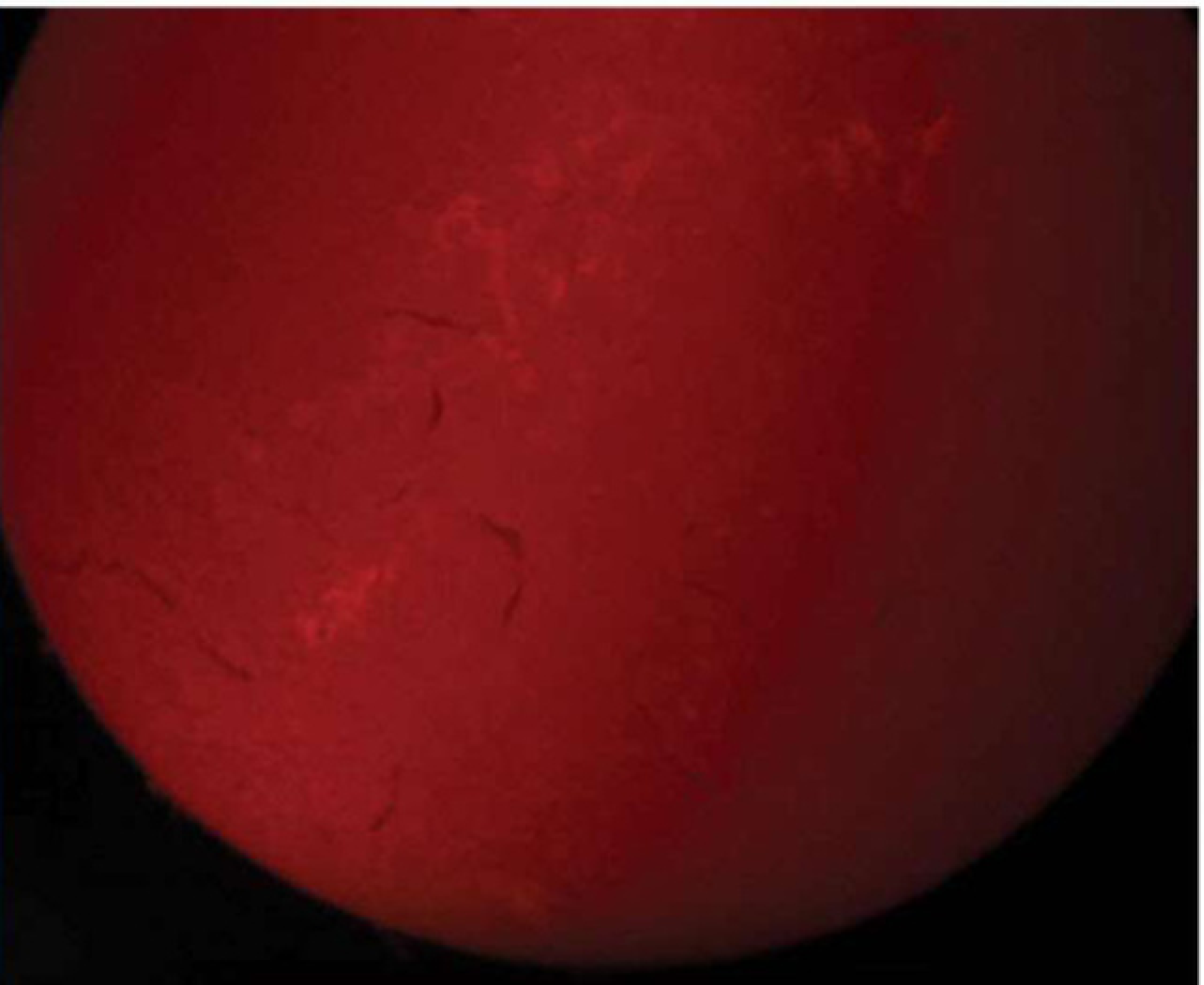
Sarah & Simon Fisher



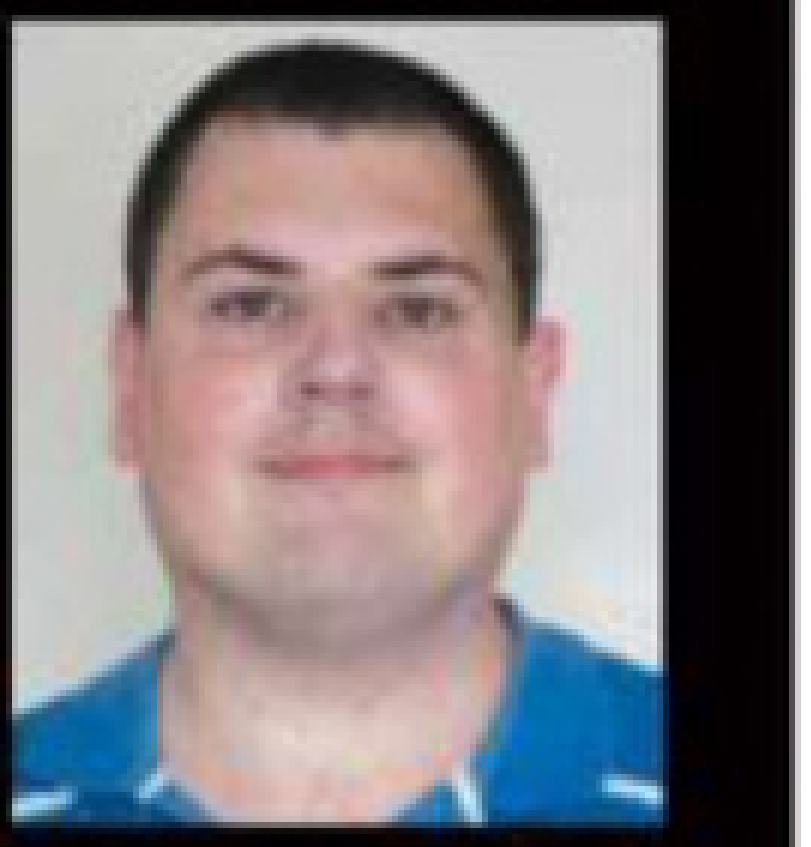
Worcestershire, UK
Telescope: Sky-Watcher Skymax 127 Maksutov-Cassegrain

"When the skies have been favourable, Simon and myself have been getting some brilliant shots. All of the images here have been captured with our Canon 600D attached to a Sky-Watcher Maksutov-Cassegrain 127mm telescope from our back garden.

"We were absolutely thrilled with the capture of the International Space Station. While Simon was manually tracking through the finderscope, I watched on the live view screen of our Canon 600D - as it zoomed across the screen, I clicked away."



Neil Cuthbertson



Derbyshire, UK

Telescope: Sky-Watcher 5" Maksutov-Cassegrain / Lunt 60THa double-stacked solar telescope

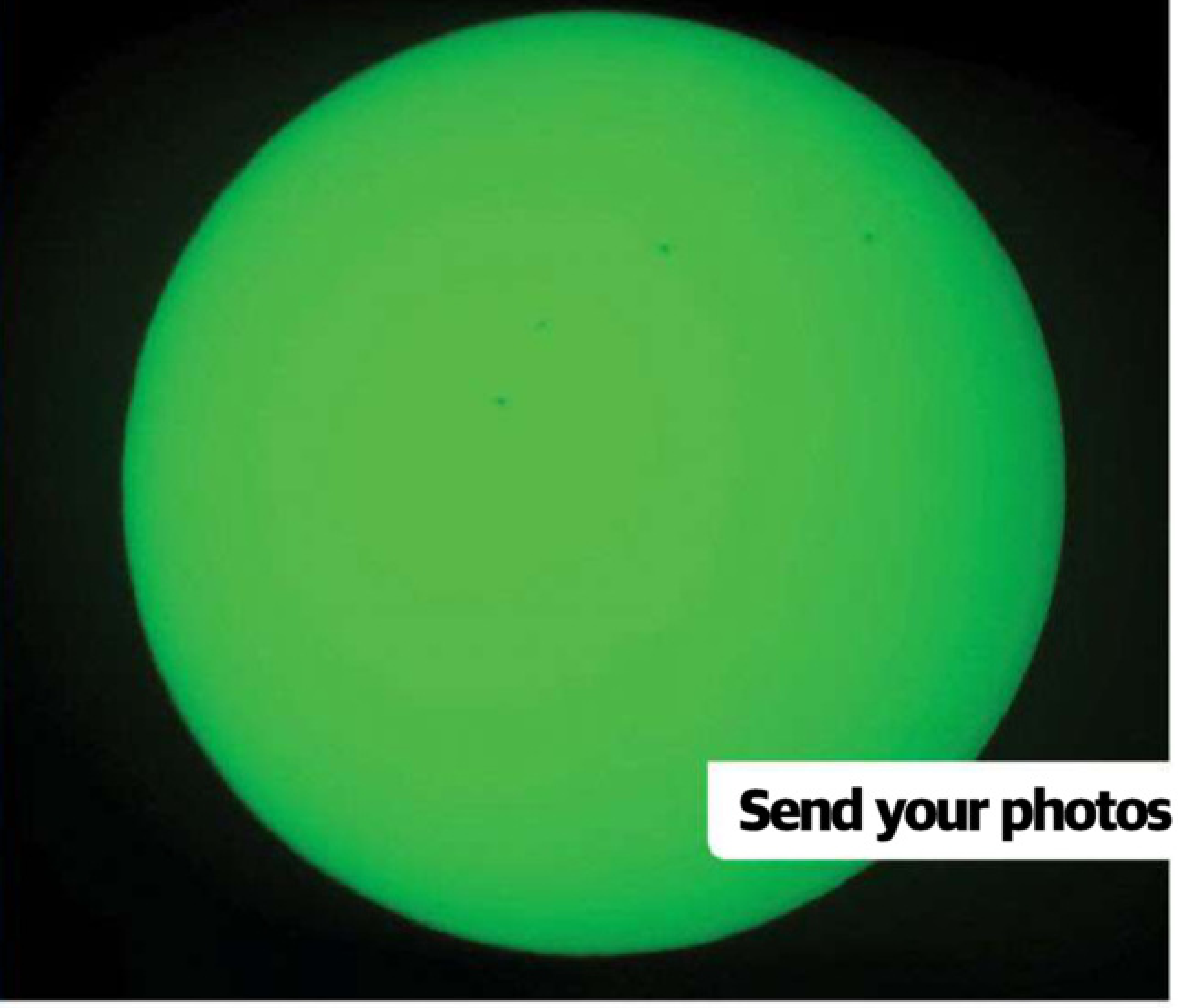
"I'm a member of the Ilkeston and District Astronomical society. I took a shot of the surface of the Moon using my Canon 400D through a Sky-Watcher 5" Maksutov-Cassegrain telescope using ISO 400 and an exposure time of 1/250sec. During the day, I imaged the Sun in H-alpha and managed to catch surface detail and prominences using a Canon 60D, set to ISO 100 and an exposure time of 1/80sec."

Gary Colville

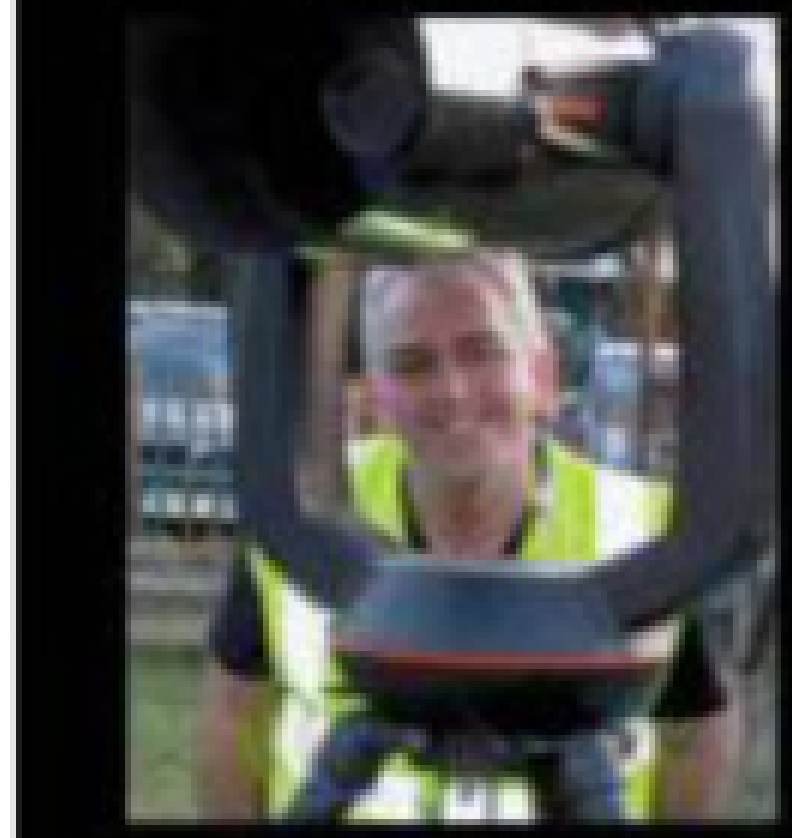
Warwickshire, UK

Telescope: Celestron 127SLT

"Popping on a homemade white light filter, an ultraviolet filter and a solar continuum filter onto the 25mm lens of my new Celestron 127SLT, I turned my attention to our nearest star. Using my mobile phone's camera, I managed to capture this image, where you can clearly see sunspots as well as the darkness of clouds just creeping across the front of the Sun."



Andy Lee



West Sussex, UK

Telescope: N/A

"This is a combined image of two frames, one of Mars and of the Moon. The Moon was so bright that I lost Mars and so a second shot was taken, to overexpose the lunar surface but show Mars nicely. Both frames were merged in Photoshop CS3. On a fixed tripod, I used a Canon 50D with a Canon 70-300mm lens at an exposure time of 1/2,000sec and ISO 100 to capture the Moon. Mars was taken with the same exposure time and for one second."

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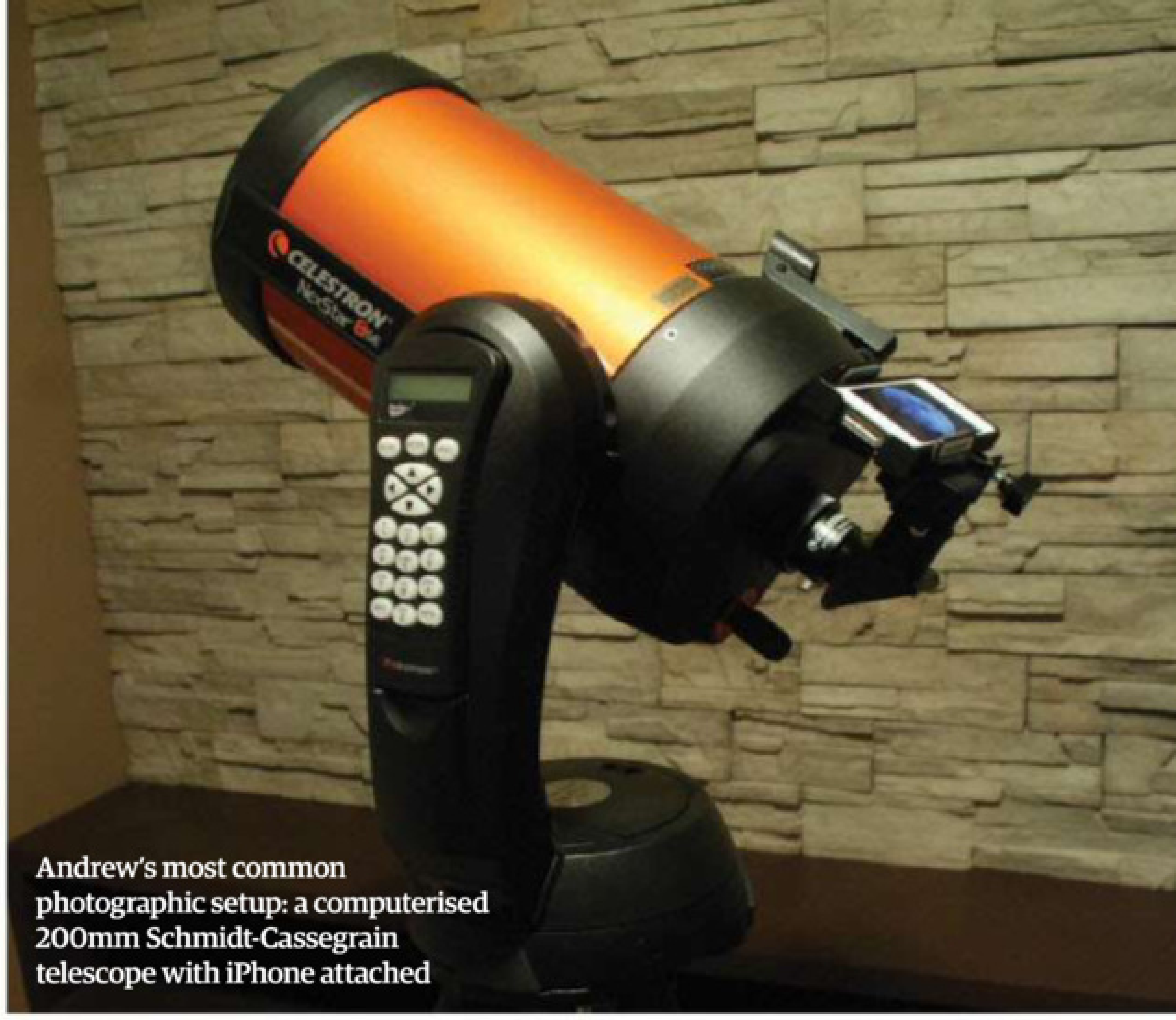
Stargazing stories

Email the story of how you got into astronomy to **photos@spaceanswers.com** for a chance to feature in **All About Space**



Andrew's most common photographic setup: a computerised 200mm Schmidt-Cassegrain telescope with iPhone attached

Andrew Symes

Location: Ontario, Canada
Twitter: @FailedProtostar
Info: Astronomer for 17 years
Current rig
Telescope: Celestron NexStar 8SE
Mount: Computerised single-fork arm mount
Other: Coronado Personal Solar Telescope (PST), Nikon D7000 DSLR, iPhone 4s, Celestron 15x70 SkyMaster binoculars

"I've been hooked on space and astronomy since 1994 when, at 15 years old, I saw a magazine cover that showed dark scars on Jupiter from the recent comet Shoemaker-Levy 9 impact. I was amazed that amateur astronomers took the photos I saw with backyard telescopes and I wanted to do something like that myself.

"I read all the library books on astronomy and stargazing that I could get my hands on and began to explore the night sky with binoculars. After receiving my first telescope – a 60mm refractor – as a Christmas present, I was quickly dazzled by Saturn's rings, the craters of the Moon and the moons of Jupiter.

"At age 17, I decided to try my hand at astrophotography. I borrowed my father's 35mm camera, bought some slide film (this was before the age of digital photography) and managed to take a few properly exposed photos of the Northern Lights...

"I then purchased a new telescope, a 130mm reflector, and was thrilled by the Ring nebula in Lyra, the M13 globular cluster in Hercules, the Andromeda galaxy and of course the Orion nebula.

"Today I own a computerised 200mm telescope that allows me to photograph and share my images of the night sky. For the past three years I've attached my iPhone to the eyepiece to post images of the Moon, Sun, planets and even the Orion nebula online. My photos are often shared by others on Twitter, and it's been extremely rewarding to receive positive comments from non-astronomer friends and family who had no idea that "ordinary people" could see so many amazing celestial objects from their backyard!" ●

Andrew's top three tips

1. Use an adapter

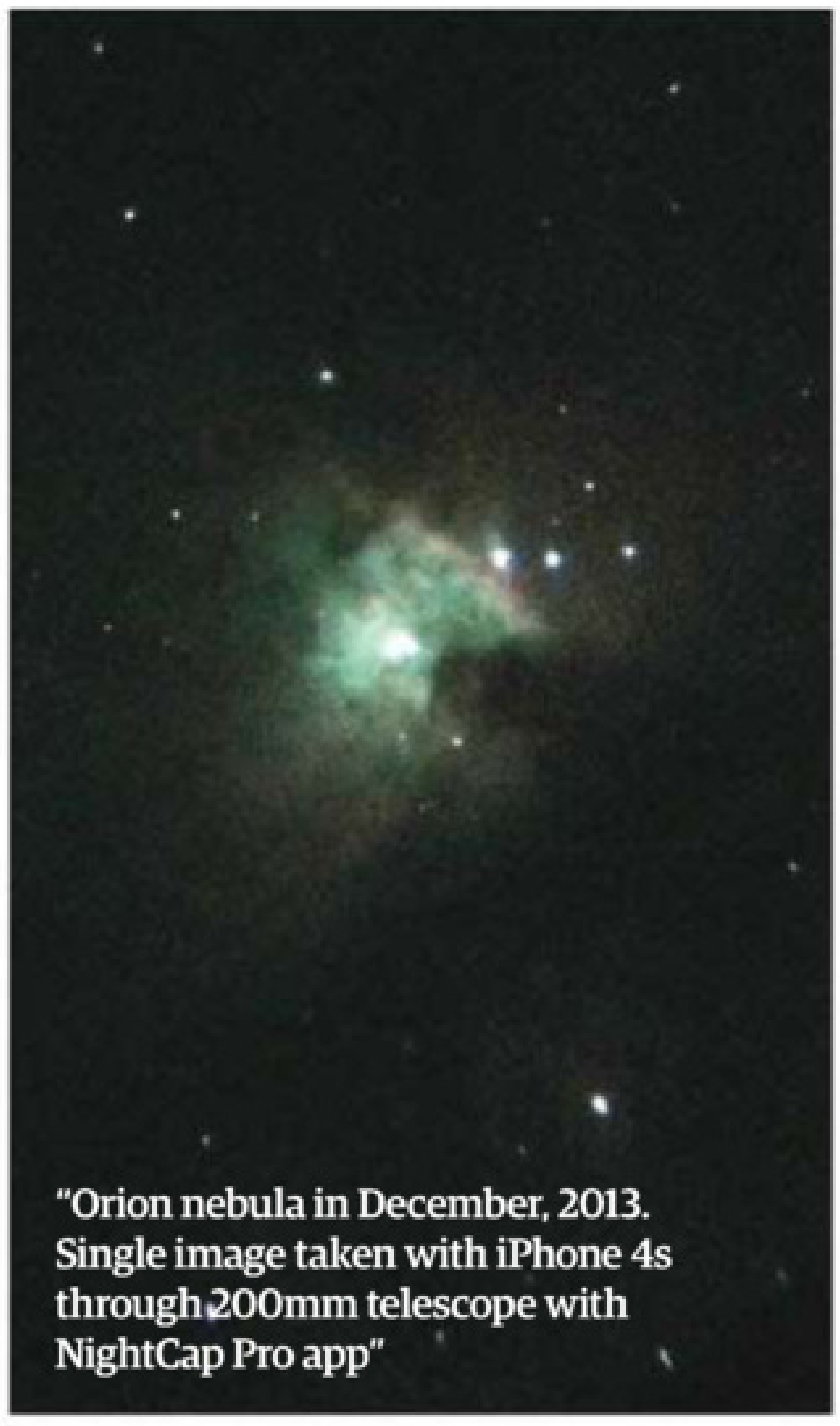
It's very difficult to hold a smartphone steady at the eyepiece of a telescope, so it's worth investing in a special adapter to do it. Many are available for purchase online.

2. Eyepiece filters

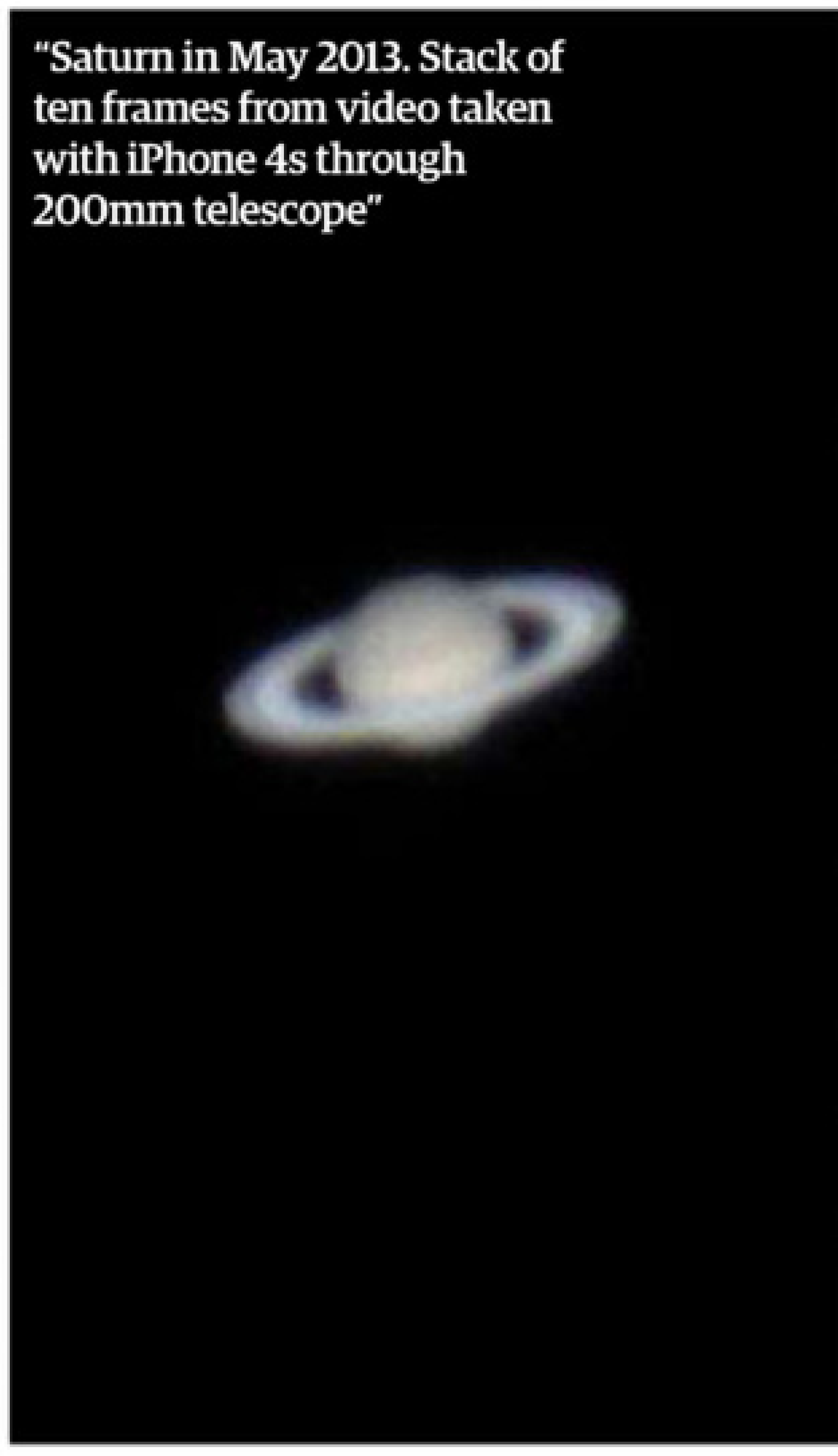
Most smartphone cameras have limited exposure controls, so use a variable polarising Moon filter to properly expose the Moon and bright planets.

3. Record video

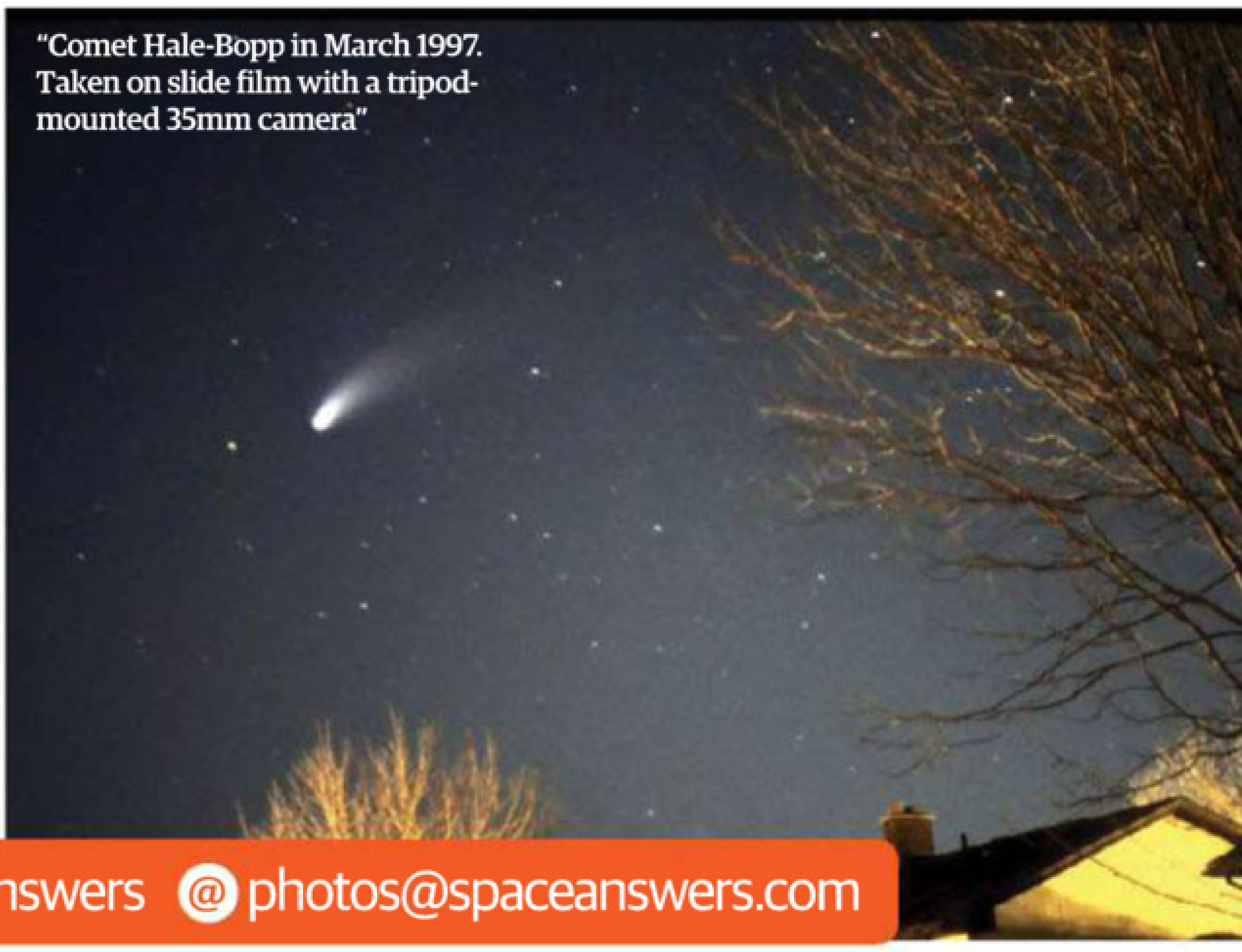
Once you're able to take steady, properly exposed images, record short videos of the planets. Those video frames can then be stacked to show additional detail.



"Orion nebula in December, 2013. Single image taken with iPhone 4s through 200mm telescope with NightCap Pro app"



"Saturn in May 2013. Stack of ten frames from video taken with iPhone 4s through 200mm telescope"



"Comet Hale-Bopp in March 1997. Taken on slide film with a tripod-mounted 35mm camera"

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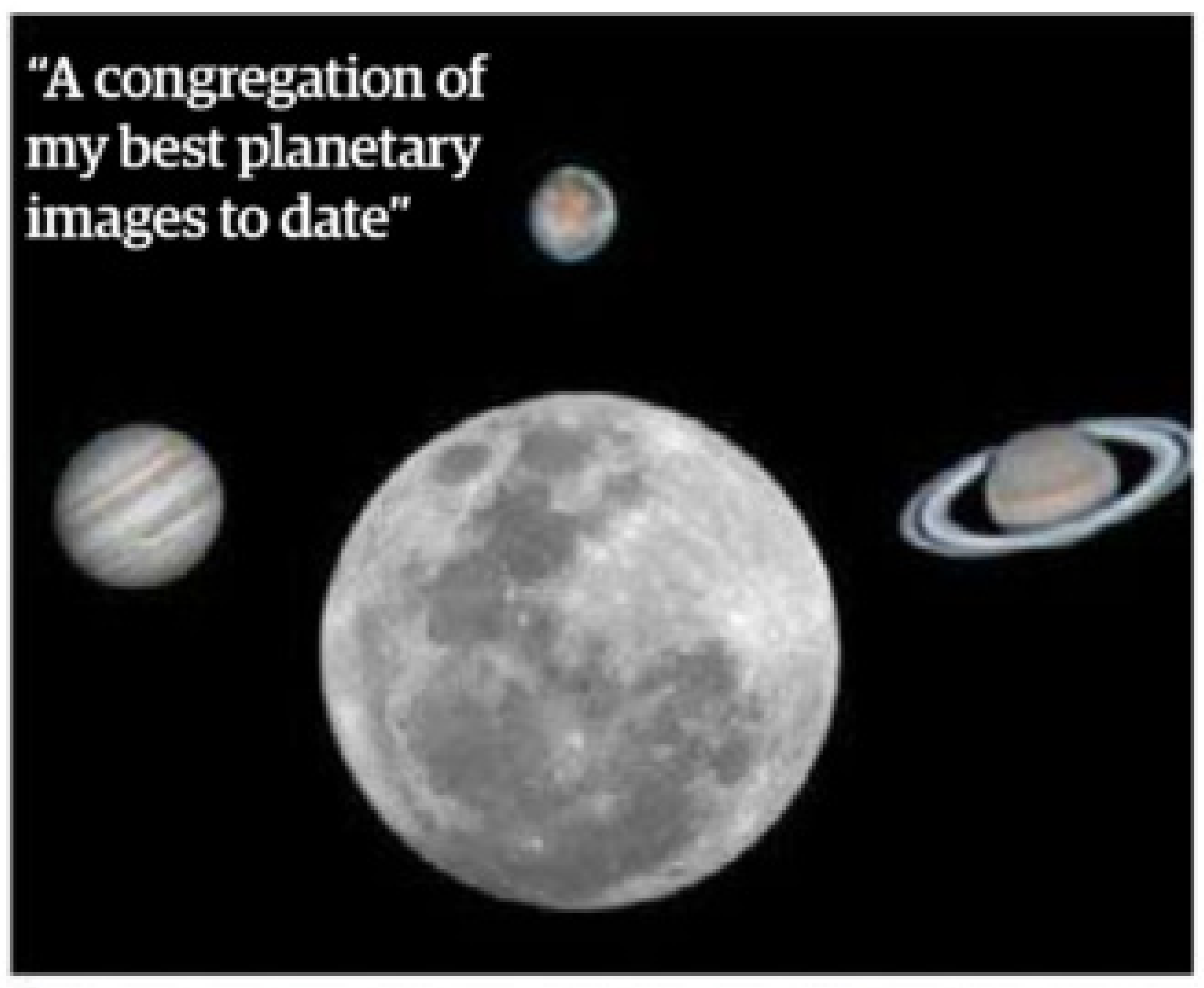
"The Horsehead and Flame nebulas (NGC 2024). This is probably my best DSO picture"

"My favourite galaxies - M81 and M82"


"A congregation of my best planetary images to date"

"The Rosette nebula... This nebula is beautiful and full of dust, gas and stellar nurseries"

"The Orion (M42) and Running Man (NGC 1977) nebula. I love this area of the sky!"

Bill Schlosser

Location: Michigan, USA

Twitter: @Starman_63

Info: Astronomer for 20 years and astrophotographer for the last five years

Current rig

Telescope: Meade 14" f/8 SCT, Orion 180mm Maksutov-Cassegrain, Astro-Tech AT65EDQ

Mount: Celestron CGE Pro on homemade pier

Other: DSO camera - QSI 683 WSG-8 filled with Astrodon LRGB and Ha/O3/S2 filters and a Lodestar guide camera. Planetary cameras - Celestron Skyris 618M with Orion 5-position manual filter wheel and Astronomik L-RGB filters, Imaging Source DBK 21AU618.AS colour

"The first time I looked through a telescope, it was an old Meade 8" reflector on a motorised mount. My friend had Jupiter in the eyepiece and it was seriously life-changing for me. I grew up as a child in the Mercury / Apollo days (yes, I wanted to be an astronaut) and loved space. My father used to take us to Lake Erie outside Toledo, Ohio, to gaze at the stars. After that first look at Jupiter, I was hooked. I joined the US Navy after graduating high school and was stationed in San Diego, California. Being on board a darkened ship in the middle of the Pacific Ocean is something everyone should experience. The Milky Way can be so bright it can cast shadows!

"In 1994 I joined the Toledo Astronomical Society and remember seeing Comet Shoemaker-Levy 9 hitting Jupiter and leaving those huge darkened scars on the cloud tops. I did not own my own telescope until 1996 - I purchased a second-hand 8" Meade LX200. I remember looking at Comet Hale-Bopp through it the very following year.

"I got away from astronomy for many years until 2007, when I purchased another Meade - a brand-new 10" LX200! Then it started - and I believe all amateurs go through this - I began buying and selling one scope after another. First it was Ritchey-Chrétiens (Astro-Tech), then refractors (Including a TEC 140), Maksutov-Cassegrains (Meade ETXs, then an Orion 180mm) [until I got] my current 14" f/8 Meade.

"In 2009 I wanted to try my hand at astrophotography. I've gone through a huge learning curve and many different cameras until the ones I own now. I'm friends with Jason Ware on Facebook - he takes amazing DSO images - and I look at Damian Peach's planetary shots and these are what I'm working on duplicating now - albeit with a long way to go." ■

> "I've gone through a huge learning curve and many different cameras"

Bill's top three tips

1. Join a local club

Make sure you ask questions - many astronomers love to share experiences and equipment that will allow you to choose the right telescope.

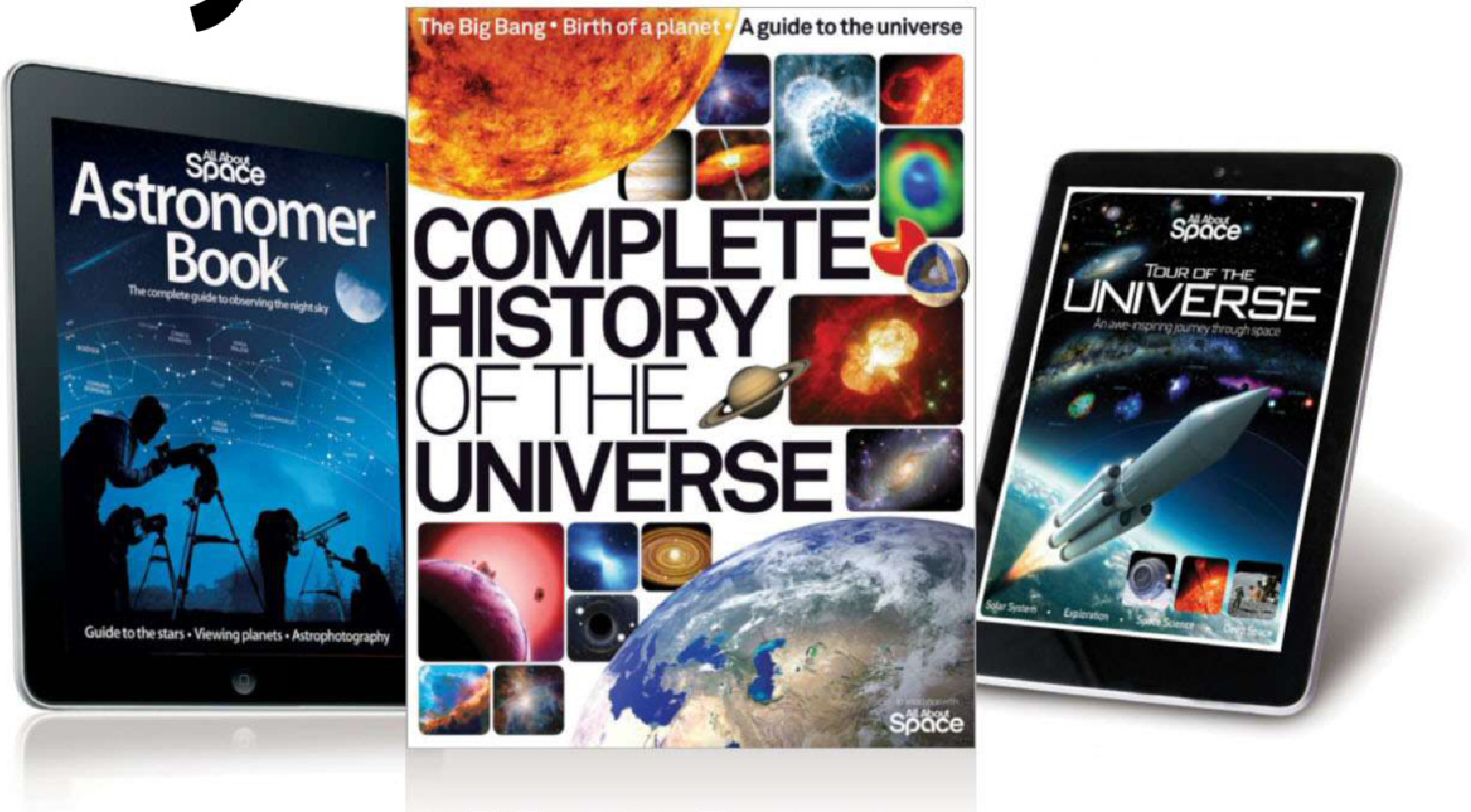
2. Make sure you have a good mount

If you don't have a good and steady mount, your results will suffer. Learn to align it correctly - it's the most important thing you can do.

3. Be patient!

I almost gave astrophotography up right at the start. But with the advent of many tutorials online, on sites such as YouTube, it's easier than ever now.

The universe in your hands



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WIN
OLIVON T650 SPOTTING SCOPE
COMPLETE WITH TR150-10 TRIPOD

WORTH £369!

Start your exploration of the night sky with this latest spotting kit

Courtesy of Optical Hardware (**www.opticalhardware.co.uk**), we've got the newly launched Olivon T650 spotting scope combined with a TR150-10 tripod up for grabs!

The T650 features a multi-coated, high-resolution, 16-48x zoom eyepiece along with BAK4 prisms for clear and crisp views. It's perfect for those starting out in astronomy, but also ideal for bird-watching and digiscoping. Its 1.25" standard eyepiece fitting enables telescope eyepieces to be attached, which can target objects such as open clusters, planets and the Moon.

Combined with its lightweight, fully waterproof and fog-resistant design, this spotting scope, teamed with a three-way pan Olivon TR150-10 tripod, ensures the best in basic but rewarding astronomy.

To be in with a chance of winning, all you have to do is answer this question:

Which star type is the hottest?

A: B-type B: O-type C: G-type

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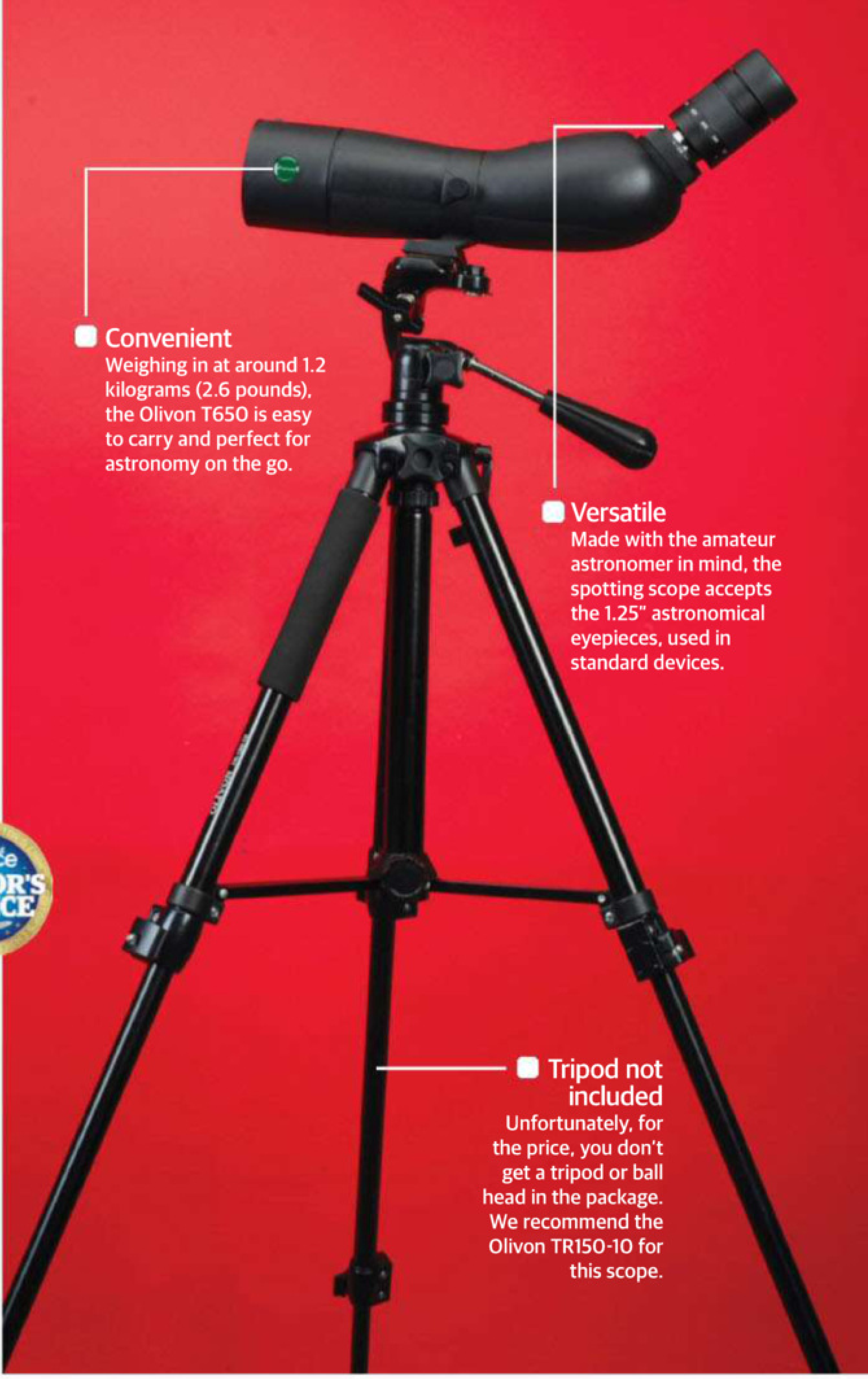
Olivon T650 spotting scope

This lightweight telescope alternative could be just the thing for flexible observing



Convenient
Weighing in at around 1.2 kilograms (2.6 pounds), the Olivon T650 is easy to carry and perfect for astronomy on the go.

Versatile
Made with the amateur astronomer in mind, the spotting scope accepts the 1.25" astronomical eyepieces, used in standard devices.

Tripod not included
Unfortunately, for the price, you don't get a tripod or ball head in the package. We recommend the Olivon TR150-10 for this scope.

While the 65mm ED glass lens isn't large enough for advanced astronomy, amateurs will be thrilled with the basic views that it can often provide

A 45-degree angle provides effective digiscoping and orientation to the heavens

Spotting scope advice

Cost: £239 / $N/A
From: www.opticalhardware.co.uk
Type: Angled
Aperture: 65mm
Zoom eyepiece: HR 16-48x

Spotting scopes aren't generally associated with professional astronomy, but the Olivon T650 provides the perfect middle ground between a pair of binoculars and a dedicated night-sky telescope.

While this spotting scope's 65mm objective lens limits it to easy-to-spot objects, such as the Moon and the brightest stars and planets, we were not disappointed as we exchanged the removable 16-48x eyepiece for a 10mm Plössl and turned the spotting scope to a third-quarter Moon. We were delighted to pick out excellent, crisp detail of the lunar mare and craters along the Moon's terminator and edge in extremely high resolution.

We also noted that the nitrogen-filled body and the compact design meant the scope had cooled quickly and we experienced no fogging. Its weather-proofing, unlike most telescopes, also makes it ideal for use in the field.

The Olivon T650 isn't aimed at pure beginners, the price for just the tube without the tripod is a good indicator of that. However, we felt that its lightweight yet sturdy design, high-resolution views and ease of use are huge selling points. If you're an avid nature-watcher and have only just begun dabbling in astronomy, then this is the spotting scope for you. If you're very focused on astronomy, on the other hand, then we recommend purchasing a cheaper pair of binoculars or a dedicated telescope.

Astronomy kit reviews

Must-have products for budding and experienced astronomers alike

1 Book
Turn Left At Orion (4th Edition)

Cost: £23 / $30
From: www.cambridge.org

Any question you could have in finding your way around the night sky is answered in this essential guide. From the novice, all of the way through to the seasoned astronomer, the way this book has been illustrated means it's suitable for all.

It's common that beginners will buy a telescope and not really know much about using it. Authors Guy Consolmagno and Dan Davis solve this problem by helping you find the most interesting things in the night sky, whatever the season and whatever the hemisphere. What's more, plenty of information on specific objects is an excellent and thoughtful addition.

Opening the book under a red flashlight, we found the star charts weren't washed out – this is vital if you want to use this guide during an observing session without ruining your dark-adapted vision.

2 Binoculars
Helios Nature Sport Plus 10x50WA

Cost: £80 / $N/A
From: www.sherwoods-photo.com

Sweeping the Milky Way and targeting a selection of star clusters in June's night sky, we were treated to crisp and clear views of a selection of targets during our observations.

While the optical capabilities of the device were excellent for the price range, we did find the shape of the exit pupils quite odd since they weren't completely round. Also, because they weren't nitrogen-filled we worried that, over time, moisture might get into the binoculars without adequate protection.

With the 6.5-degree angle design, multi-coated optics and BAK4 prisms, we able to target globular cluster M13 in constellation Hercules and could even pick out a fuzzy blob with a well-defined centre of stars in a right-angled triangle. A couple of seventh-magnitude stars were just visible, while Mars and Saturn appeared as stars devoid of any colour-fringing.

3 Tripod
Olivon TR150-10

Cost: : £100 / $114
From: www.opticalhardware.co.uk

At this relatively low price, we weren't expecting this Olivon tripod to be outstanding quality. However, on receiving the TR150 and TRH-10 all neatly included in a case, we were impressed with the design and ease of use when fixing a spotting scope or camera to it.

The TRH10 three-way head enabled us to pan and tilt, but the orientation from landscape to portrait was a slightly stiff one and we found that we had to steady the very lightweight tripod before we could make any changes. However, once positioned, the rigidity was welcomed and ensured stable views through a spotting scope and DSLR camera.

Granted, this tripod didn't match up to the more-expensive versions that you may have come across, but if you've just got yourself a spotting scope or are new to nightscape astrophotography, then this tripod is certainly value for money.

4 App
Star Walk 7.0

Cost: £1.99 / $2.99
From: iTunes

If you have difficulty finding your way around the night sky and you can't afford a GoTo, then Star Walk is the next best thing. This app is able to work out the exact location, as well as the celestial object that you point your iPhone at. Of course, it works in reverse too, by helping you to find the object that you wish to locate. Using a GoTo, we followed up the RA and Dec co-ordinates to see how accurate it was. We were impressed to find that, on harnessing the iPhone's GPS capabilities, it was almost spot-on.

We're based in the Northern Hemisphere, but that didn't stop us from checking out the stars and constellations down south, as we pointed Star Walk downwards and were treated to the positions of countless objects in the other hemisphere. The touch screen enabled us to learn more about the objects we were seeing – excellent for learning all about the night sky.

Chandrasekhar poses for photographs outside the University of Chicago, having just received the 1983 Nobel Prize in Physics, joint with William Fowler

Subrahmanyan Chandrasekhar

The Nobel Prize-winner who rewrote the rule book on stellar dynamics

That name might ring a bell if you don't know it already: his most-recognised legacy was the Chandrasekhar limit. This describes the maximum mass of a white dwarf star, although this Indian national and naturalised American contributed much more to physical science.

Born into a family of ten siblings in the Punjab province of India, in October 1910, Subrahmanyan Chandrasekhar's stellar career in physics got off to an early start. His lineage could be traced back through a line of academics and intellectuals: his grandfather was a mathematics professor, while his paternal uncle was Sir Chandrasekhara Venkata Raman, who earned the Nobel Prize in Physics in 1930 for his work on the scattering of light. His name is now given to the phenomenon known as Raman scattering that he discovered.

Chandrasekhar's early interest in physics is credited in part to his mother, who herself was keen on promoting academic pursuits in her children. His education took him through one of the oldest secondary schools in south India, the Hindu High School in Chennai, before he moved on to Presidency College. It's here he wrote his first paper, called 'The Compton Scattering And The New Statistics'. He graduated in June 1930 and was awarded a scholarship in July to study at the University of Cambridge, England. It was here he began to make waves in astronomy.

As someone who was primarily concerned with systems and the methods by which scientists study and structure their research, Chandrasekhar was able to turn his intensely logical mind to bringing greater definition to existing theories in many different areas. He studied under the great quantum physicist Paul Dirac, who recommended he spend the last few months of his post-graduate studies in Copenhagen, at the Institute for Theoretical Physics. Here, Chandrasekhar met another great 20th-century physicist: Niels Bohr.

By this point his work had attracted some attention and earned him several awards. He gained a fellowship at Trinity College, Cambridge, where he had a dispute with Sir Arthur Eddington, who challenged Chandrasekhar's mathematical interpretation of degenerate physics in dwarf stars. This was a precursor to the theory of black holes and, at the time, a seemingly ridiculous concept (even though Chandrasekhar would later be proved entirely correct). The dispute, combined with the spread of Naziism across Europe in the late 1930s, prompted Chandrasekhar to look overseas for work and he decided to move to America.

In 1937, Chandrasekhar was employed as an assistant professor by the University of Chicago, where he remained for the rest of his career. He turned his mathematical prowess to the war effort in the early 1940s, contributing to the manufacture of materials that would ultimately become part of the world's first atomic weapons. Following World War II, he became an American citizen and continued to make considerable contributions to physics and astronomy. He studied black hole theory in the 1970s, resulting in a paper on 'The Mathematical Theory Of Black Holes'. In 1983, Chandrasekhar was finally vindicated in his 50-year-old argument with the late Eddington, as his paper on the upper threshold of white dwarf stars won him the Nobel Prize in Physics.

Chandrasekhar died of a heart attack in his adopted city of Chicago on 21 August, 1995, aged 84. His work formed the core tenets of stellar dynamics and today is central to understanding the evolution of stars and what happens when they die. ■

All About Space

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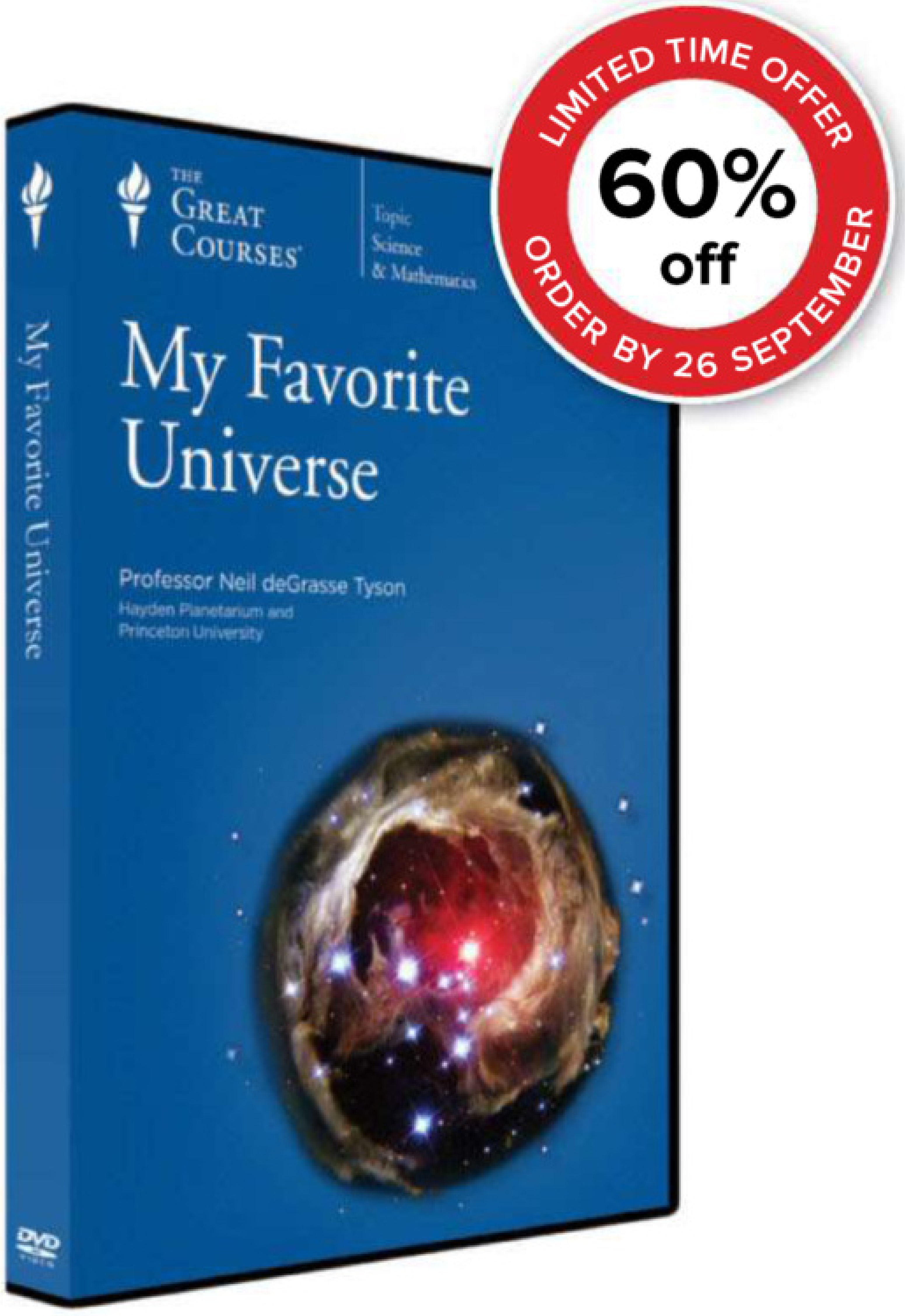

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